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- Materials
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- European Countries Commit to Cleaner Manufacturing - 499

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ORGANIZATIONAL INDEX

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ESN INFORMATION BULLETIN

This publication is an official publication of the Office of Naval Research European Office. It describes research that is being conducted in Europe and the Middle East.

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93-08

In This Issue. . .

European Countries Commit to Cleaner Manufacturing

by Michael Overcash, former Liaison Scientist for Chemical Engineering and the Environment at the Office of Naval Research European Office. He is a Professor of Chemical Engineering at North Carolina State University.

KEYWORDS: environment; chlorofluorohydrocarbons; BRITE/EURAM; clean technologies; revitalization

INTRODUCTION

Many European government-funded research and development (R&D) activities are focused on the environment. "Cleaner manufacturing" is one of these issues, with both European Community (EC)-wide and individual country resources being directed at advancing knowledge in this field. Within this area, central themes include chlorofluorohydrocarbons (CFC) replacement, plastic use and reuse, and heavy metal minimization—either in product design or through greater process efficiency. The magnitude of direct European government support to basic research and to engineering development is large. It is generally comparable to equivalent U.S. efforts by the Environmental Protection Agency (EPA), the National Science Foundation (NSF), the Department of Energy (DOE), and the Department of Defense (DoD). European governments are not reluctant to directly fund industrial process innovation; they perceive it to be good for the environment.

Equally important, these governments feel that it makes European industry more competitive—both now and in the future, as environmental factors become even greater in regulations or consumer preferences. The goal is steady, incremental improvement, with emphasis on reducing the economic risk of manufacturing processes or product changes. European attention is focused on virtually every industrial category. Priority for funding is toward innovative ideas and broader utilization of viable results. This does not generally mean broad publication but rather, concerted work by similar manufacturing facilities to adopt changes.

The objective of this study has been to describe, in summary terms, the specific cleaner manufacturing technologies as seen in the R&D programs of federal or corporate organizations in Europe. Preventative and re-use approaches are the focus. It should be noted that a lot of pollution control R&D is occurring in European countries, but this is not covered here. The goal is to provide contacts and identification for the reader to pursue specific interests in greater detail. The author is also prepared to assist the reader in contacting and utilizing the network of European funding agencies and organizations described here.

EUROPEAN COMMUNITY

BRITE/EURAM II - Industrial and Materials Technologies

The EC currently has 15 research and technology development (RTD) areas; one of these—BRITE/EURAM II for the third framework—is devoted to industrial revitalization. This program covers the 1991-1994 timeframe. The objectives here are to:

- increase the competitiveness of European producers and user industries;
- strengthen European economic and social cohesion; and
- promote the scientific, technological, and economic integration of European industry.

Small and medium enterprises are the primary participants, although many of these are of significant economic size. Large corporations also participate. Ensuring a steady flow of quality engineers and scientists for the continued advancement of industrial technology is also a goal. The dissemination and exploitation of results are important, especially as these lead to the development of standards and user specifications. The overall EC budget for RTD is about U.S. $7 billion for this three-year period. European Community funds are matched 1:1, with individual country funding thus doubling this budget. For BRITE/EURAM II, the funding for RTD is U.S. $0.8 billion for the same period. The Director for Technological Research in the BRITE/EURAM program is **A. Garcia Arroyo (tel: 32-2-295-2345, fax: 32-2-295-8046)**.

Each framework of funding builds on an evolving mix of topics and priorities. For the 1991-1994 program, the outline of research areas is as follows:

Raw Materials and Recycling (12% of budget)
- exploration technology
- mining
- mineral processing
- recycling and recovery of industrial waste
- recycling and recovery of advanced materials

New and Improved Materials (35%)
- metal and metal matrix composites
- ceramics, ceramic matrix composites, and advanced glass
- polymer and polymer matrix composites
- magnetic materials
- high-temperature superconducting materials
- electrical and ionic conducting materials
- optical materials
- biomaterials
- packaging
- new construction industry materials

Design and Manufacturing (45%)
- design of products and processes
- manufacturing
- engineering and management strategies for the whole product life cycle

Aeronautics (8%)
- environment-related technologies
- technologies of aircraft operation
- aerodynamics and aerothermodynamics
- aeronautical structures and manufacturing
- avionic systems
- mechanical, utility, and actuation technologies.

Within BRITE/EURAM, a number of current projects represent clean technologies; these may describe, in general terms, the future direction of new funding. The projects are mostly in the raw materials and recycling area, which at U.S. $100 million for the three-year period would be expected to fund about forty separate projects.

Projects

The following descriptions highlight the clean technology topics covered under BRITE/EURAM; recognize that as new projects are funded, new priorities will evolve. One of these overall themes is environmentally friendly polymers. Four projects reflecting this effort are aimed at plastics. Biodegradability is studied as a general phenomenon, with emphasis on the basic factors controlling such decomposition. Polyamide polymers are also studied as a specific case for biodegradability. A third project examines bacterial polyesters in regard to the melting, forming, and orienting of these polymers for containers. This is followed by studies of the biodegradability of these products. A fourth project uses a chemical approach in which blends of thermoplastic resins are investigated. The properties of the resulting heteropolymers are examined based on a lot of characterization, both of the input blend and the final products. This is a vital issue; mixed plastics are common in the field of polymer recycling.

Two polymer coatings research efforts are also included in the environmentally friendly polymers funding. For difficult high-performance applications, research is underway to find a high-solids, isocyanate-free paint material. A second project focuses on water-based paint improvement for current limitations that include higher permeability to water and other chemical vapors, occurrence of pigment flocculation, and insufficient gloss finish due to poor rheology on application. Specific research objectives are aimed at significant improvements in the understanding of these phenomena so that chemical and physical paint formulation changes can be offered. The goal is to considerably expand the range of potential use for water-based paints. In a different area, the evolution of plastic composites is examined as a major industrial trend. This research project focuses on the ultimate demand to recycle these heterogeneous materials as the use of composite material products increases. In contrast, the pressure on polyvinyl chloride (PVC) suggests that use of this polymer will decline. Thus one research effort is aimed at providing substitutes for current foil applications of PVC.

A paper-type packaging material is envisioned, with coatings to yield properties similar to PVC.

Other pollution-prevention BRITE-EURAM research projects emphasize and demonstrate the real diversity of opportunities for industrial change. These include

- Ecopave - research to understand the impact on basic paving material characteristics when nonstandard aggregate or additives are included. These new inputs are from the pressure to recycle other materials such as building debris, paint residues, ceramic wastes, etc. This knowledge can thus broaden the recycle potential.
- Gypsum is increasing from the flue gas cleanup to remove sulfur dioxides. This must be landfilled unless expanded markets are developed, hence the research on gypsum and gypsum/pozzolanic materials for the building industry. Basic studies are thus defining the chemical, strength, and durability properties of this new gypsum supply.
- Restoring the European leather industry on the basis of environmentally clean technology is the goal of another research effort. A great deal of basic research is conducted to achieve nonchrome alternatives, to significantly increase the viability of all byproducts, and to improve the quality and production rates.
- Acids are widely used in industry and often become contaminated with heavy metals. While research is common to recover the metals, one BRITE-EURAM project emphasizes acid recovery. The economics of acid recovery appear more favorable now, and a membrane approach has been selected for research. The aggressive acid waste environment is a challenge. Membranes with radiochemical grafting are examined in dialysis and electrodialysis contexts.
- As the chemical industry moves further in reaction efficiency to prevent wastes and byproducts, catalysts are vital. Recognizing that these will increase in quantity and diversity, EC research has focused on the basic science needed to recover and recycle such catalytic materials. Rhodium is the initial system for study as this catalyst is used to make octane boosters and other chemicals from the direct conversion of synthesis gas.

BRITE/EURAM Summary

The current BRITE-EURAM program and the third framework are to contribute directly to research in clean technologies. Their emphasis is on steady improvement of chemicals and products that are viewed as environmentally friendly. Many projects appear to have examined the current barriers to industrial change (such as a limited market for gypsum, which is rapidly increasing from sulfur dioxide clean-up of combustion gases). Then, research attempts to provide further information to identify solutions. These research efforts are a good mix of chemistry, engineering, and manufacturing.

GERMANY

MINISTRY OF RESEARCH AND TECHNOLOGY (BMFT)

The environment, climate, and safety R&D annual budget of the BMFT is about $300 million. Environmental technology R&D is about $100 million of this budget, slightly less than that for ecological R&D. Within the BMFT the principal agency responsible for cleaner manufacturing is the German Aerospace Research Establishment (Deutsche Forschungsanstalt fur Luft -und Raumfahrt, DLR). Budgets for cleaner technology are not clearly identifiable, but are estimated by BMFT personnel at $15 million.

Projects in cleaner technology generally comprise two or more industrial partners, together with a university or institute partner. Over a two-to-three-year project period, typical budgets are $600,000 provided from the government and $400,000 additionally from industry. Some of the money from the government is given directly to the industry. For large corporations, the government portion is reduced to about 40%. Most of the ideas or proposals originate in industry, with university or institute researchers being involved for specific expertise. Overall, BMFT records that 75% of the R&D results have been adopted by more than the original industrial partners. This is a very solid technology transfer record.

At the DLR, the funding from the Federal Ministry of Research and Technology is administered under the Environmental Protection Technology Group (UST). A specific focus within UST is the Clean Technology and Industrial Wastes Gases, which comprises the bulk of research projects on pollution prevention (contact **Dr. Gunter Panzner, tel: 49-228-3821-178, fax: 49-228-3821-229**). This organization coordinates about 150 projects conducted throughout Germany. Although a very diverse collection of research and development efforts are being pursued, these can be classified into six topic areas. In each of these, the principal focus is prevention or reuse, with a solid emphasis on improved process understanding and field trials of technologies.

The first category, and probably that with the greatest current emphasis, is referred to as Low-Emission Processes in Industry. Although these projects span many industries, the general characteristics are process development utilizing alternative chemical routes or achievement of greater efficiency through process understanding. These efforts directly support industry/university initiatives. There is no reluctance to provide government assistance in achieving new results and lowering the economic risk of potential change. Even large industry participates.

Within the Low-Emission Processes theme are

- Paper and Pulp Production (4 projects)
- Textile Finishing and Leather Production (2)
- Electroplating (9)
- Coating and Surface Treatment Processes (4)
- Metallurgical (1)
- Production of Building Materials, Glass, and Ceramics (1)
- Food (3)
- Low-Emission Heating Units (1)
- Water Treatment Chemical Production (1).

There are detailed descriptions of these projects and, like similar funded efforts in the past, a report is required at the end of the study. Even though these projects are for specific processes or plants, there are significant advances in the knowledge underlying each process group. This is a transferable element that benefits the overall issue of cleaner manufacturing.

Low-emission products represent the second category of DLR projects. This is an important effort because the impact is both in manufacturing and in the marketplace. The economic implications are thus an interesting aspect of the government funding under the auspices of clean technology. In this category, three projects deal with German goals for recycling greater numbers of consumer products. These include halogen-free fire retardants for plastics in electronic equipment, recyclable lawn mowers, and television parts and assemblies for ultimate reuse. Research is focused on the limiting stage in achieving maximum recycle from a post-consumer system of collection or return. Another product research effort is on biologically degradable lubricants. This improved product would reduce impacts in wastewater and aquatic systems and improve the situation at product disassembly facilities. Lubricant applications that are targeted in this project include hydraulic systems, motors and gears, railways, and cooling agents in machining.

The BMFT concern for the replacement of CFCs is the basis for the third category of clean technology research. The emphasis is less on development of new chemicals (presumably because many researchers are active in this area). Instead this program is focused on the very important R&D needed to actually make existing replacements work. CFCs were universally used, and no replacement has this broad potential for use. Instead there are many applications, each of which must be changed, improved, or redesigned to operate efficiently with some current CFC replacement. It is this important broad R&D work that is contained in this category. There are about 30 projects; these can be grouped as

- refrigerants and heat exchange,
- alternative electronic assembly,
- glass and metal cleaning,
- polyurethane and polystyrene foams, and
- textile finishing.

This category is important since such a broad approach to a number of separate applications can achieve the effective continuation of industrial operations. In this case, the goal is actually to improve the manufacturing process so that the CFC substitution leads to greater competitiveness.

A corollary area to CFC replacement is chlorinated hydrocarbon replacement as the fourth DLR/UST category. Although not in the same regulatory arena as CFCs, these chlorinated chemicals are being examined by research projects to anticipate changes and improvements in the future. Ten projects are currently underway in this category. Actual industrial applications in this category are not clear. It appears that chlorinated solvents in chemical extraction, electrical parts production, and dry cleaning plants have been targeted. Some large corporations are involved in this research category.

The fifth clean technology category is volatile emissions of nonchlorinated hydrocarbons. There are two projects in this area, possibly indicating that the current priorities are with the chlorinated compounds. Volatile emissions from two-layer enamels for industrial coatings and the development of powder coating alternatives in automobiles are the research projects.

Plastics recycling is the sixth category focused on clean manufacturing. Research in this area appears to focus on two large challenges faced as greater and greater demands for consumer product recycling are made by the German government. The first is to expand the type of plastic products that can be recycled. Thus more diverse product groups are examined, often in which plastic is only a part of the actual item. For example telephones and computers are targeted. The second challenge is the actual recycling process, particularly for impure or mixed plastic streams. In this category, chemical techniques are preferred, with R&D on pyrolysis and hydrogenation.

Overall, the commitment by BMFT and the efforts of the German Aerospace Research Establishment is very significant in terms of funding and philosophical framework. They have a firm program involving important industrial problems, but with an objective to improve the knowledge base regarding manufacturing. This information will open new opportunities for improved process efficiency and new, environmentally friendly products.

DEUTSCHE GESELLSCHAFT FUR CHEMISCHES APPARATEWESEN, CHEMISCHE TECHNIK, UND BIOTECHNOLOGIE (DECHEMA)

As a nonprofit technical and scientific society, DECHEMA has established important overall objectives. These objectives are the advancement of chemical apparatus and machinery, chemical engineering, biotechnology, and related scientific fundamentals through research and information exchange. DECHEMA is also a part of the German Association of Industrial Research Societies (AIF), which contains all the professional, nongovernment organizations. AIF has an overall budget devoted mostly to research and development of about $400 million per year.

DECHEMA is dedicated principally to the promotion of research related to the organization objectives. Their budget is about $16 million per year, of which approximately 60% is DECHEMA funds and the rest from the German government for block support of research. Projects are typically initiated by university or institute researchers, with funding at the level of $250,000 - $350,000 per three-year project. Each project has a working advisory committee with members from industry, government, and academia. Additionally, DECHEMA is the sponsor of the ACHEMA Exhibition Congress for Chemical Engineering and Biotechnology. This world-famous exhibition was begun in 1920 and now attracts more than a quarter of a million visitors to the week-long congress, typically held in Frankfurt.

The primary research focus areas for DECHEMA are

- new materials,
- principles of catalysis,
- basics of recycling, and
- renewable resources.

These encompass the bulk of all current research investments by DECHEMA. Their overall goals are support of chemistry-related basic research at universities and the promotion of application-oriented research following the principles of market economy and respecting neutrality in regard to competition.

Of the core areas the last two are central to the issue of cleaner technologies. **Dr. J. Baselt (tel: 49-69-75640, fax: 49-89-7564201)** has been effective in including cleaner manufacturing and environment in the DECHEMA efforts.

Under the topic of basics of recycling are two foci for research: plastics, and metals and inorganics. For plastics, the research is channeled into two general areas. Plastics recycling by thermal methods is important and requires further improvement. Their effort is on better defining alterations of polymer properties (including that related to chemical additives) during recycling. Such alterations reduce recycling potential. Improved basic understanding of this deterioration is the key to new plastic properties for enhanced recycling. The second plastics recycling area is degradation of polymers to monomers and oligomers. Mechanisms for depolymerization, including biological routes, are under investigation. The inorganics recycling efforts are more product-oriented. These include recycling technologies for spent catalysts, batteries, sputter targets, filter dusts, and galvanic sludges.

Under the topic of renewable resources are a multitude of raw materials from agriculture and silviculture. The implications for the German chemical industry are important if these raw materials were available on economic terms to meet worldwide competition. DECHEMA sponsors many projects in this field; general interests are

- use of oleochemical surfactants on a broader basis;
- renewable resources for biologically degradable lubricants and hydraulic oils;
- derivatives from natural products such as starch, glucose, protein, cellulose, lignin, and fat combined to give new possible applications;
- use of natural polymers and derivatives;
- new materials using renewable resources;
- intermediates, special, and fine chemicals; and
- biotechnology for use of renewable resources.

While DECHEMA recognizes the importance of these usage areas, research is also aimed at better plant breeding for these desired renewable resources and improved conversion processes to useful chemicals.

Beyond the four primary research areas, DECHEMA has identified new foci for chemical research with a high potential for innovation. These areas are newly developing, and they believe them to have great value across many industrial sectors. This common denominator has meant DECHEMA support for research. Two of these are in the cleaner technologies field. The first is new routes in plant protection. The ecological and toxicological difficulties in finding new chemicals for plant protection are major driving forces in this field. This basic research effort examines the central nervous systems of insects to understand potential opportunities to disrupt insect behavior. Plant resistance is also a research topic, including biotechnology to improve genetic resistance. This research investment is viewed as necessary to open new opportunities for plant protection and hence assure prevention of global food shortages with minimal environmental impact from chemicals.

The second clean technology research area with high potential for innovation is carbon dioxide utilization. If chemical reactions can be found that use solar energy and convert carbon dioxide into an energy carrier (either directly in a photochemical process or indirectly in a photovoltaic approach), material utilization of carbon dioxide could contribute to a comprehensive solution of the issue of global warming. Examples cited as directions are biocatalytic conversion, electroreduction using copper or titanium dioxide electrodes, hydrogenation, and photochemical methanation using ruthenium and osmium colloids as catalysts.

These established and evolving research topics illustrate the role of DECHEMA in the specific technologies for environmental improvement through prevention. Two related, nonresearch activities also contribute to the technical base of this field. First, DECHEMA has compiled a book of German and Swiss pollution prevention case studies. These are mostly from the chemical industry. The book, *Integrated Production for Environmental Protection in the Chemical Industry*, is available from DECHEMA (ISBN 3-926959-21-5). It is available only in German. The case studies have good flow charts depicting the changes, but have little quantitative economic or chemical reduction information. The second activity is the preparation of a *Handbook of Pollution Control Suppliers*. This is a lengthy collection, mostly of pollution control. However there are sections on avoidance technologies and nonpolluting products and processes. Information is in English. This is also available through DECHEMA.

FRAUNHOFER INSTITUTE FOR FOOD TECHNOLOGY AND PACKAGING (FHG-ILV)

As an industry-focused research establishment, the FHG-ILV conducts a wide variety of fundamental and applied projects. The director is **Dr. W. Holley (tel: 49-89-149-0090, fax: 49-89-149-00980)**. Institute projects are grouped into four departments:

- Quality Assurance in Food and Packaging
- Technical Microbiology
- Process Engineering and Biotechnology
- Packaging Technology.

Within the current agenda of about 65 projects (total institute budget of about $8 million) are specific research efforts focused on advancing cleaner technology to the food and packaging industries. The following four descriptions illustrate the overall research agenda for clean technology at the FHG-ILV.

In a two-year project to be completed in 1993, researchers are undertaking a detailed mass balance of dioxins in paper mills. This is a stream-by-stream sampling and analysis program. The basic information is important to potential changes that can reduce dioxin and chlorinated organics in bleached paper products. Because paper materials are commonly in contact with food, their research is to prevent the impact of chemicals. A second research effort also seeks to reduce the use of chemicals as preservatives in association with foods. Researchers are developing biopreservation concepts in which beneficial or protective microbial cultures inhibit food-contaminating microorganisms. The product under study is delicatessen salads. Obviously, the innovative concepts would have applications elsewhere and would achieve the goals of cleaner technology.

Solvents are used in various food extraction processes and become wastes or volatile emissions. The FHG-ILV team is developing solvent-free oil extraction processes from natural materials such as seeds, plants, and residues. Rapeseed is the initial target for research. In another processing-related study, researchers are attempting to develop new packaging materials from renewable resources. Native polymers can be formed into films or foils, but they lack important packaging properties. The FHG-ILV researchers are using vacuum coating of the natural polymeric materials to achieve comparable physical and chemical barrier properties to current packaging materials.

Examined within the dimensions of a single industry, the FHG-ILV is providing research leadership to advance cleaner technology. Since they are contributing to basic as well as applied knowledge, there is ample opportunity for transfer of information to other industrial manufacturing processes.

HOECHST AG

Hoechst is a large multinational corporation that has significant presence in the U.S. As such, Hoechst has made steady progress in manufacturing to prevent chemical loss or to achieve cost-effective byproduct recovery. The driving force for prevention can easily be seen in their current cost for environmental compliance. This has risen from about 1.3% of annual sales in 1974 to more than 7% in 1992. Divided among environmental media, wastewater is about 50% of these outlays, with air and solid wastes about 25%. When conversion costs are defined as product sales value minus the cost of all raw materials, environmental compliance expenditures are about 21%.

This chemical company defines their guiding principle as: "the economical use of resources and respect for the environment have equal standing with the objective of performing more efficiently." This is an important reflection of all the factors that must contribute to a viable corporation. The staff of Hoechst have published many examples of process and chemistry changes that contribute to pollution prevention (Hoechst contact for such examples, **Dr. Claus Christ, tel: 49-69-305-5943, fax: 49-69-305-16313**). These are included in the DECHEMA book of case studies referred to previously.

Many of the Hoechst technology innovations relate to chemical manufacturing. One illustration is a contribution to the issue of CFC elimination, namely what to do with these materials when replaced from some machine or process (such as an automobile air conditioner). Worldwide, probably more than 1 million metric tons of CFCs could be considered confined or stored. Primary recycling to yield CFCs is the best choice from a materials conservation and energy point of view, but this is prohibited. Hence, secondary recovery becomes the best choice.

Hoechst has developed a secondary recovery process using thermal cracking. Temperatures between 2,000-2,600°C were needed to assure full cracking of the numerous forms of CFCs. A hydrogen/oxygen combustion gas proved optimum. This has minimized nitrogen oxide and carbon dioxide formation. Special acid-resistant materials (DIABON, a graphite) had to be used, and explosion risks are necessarily present. The product is two streams, a 50-55% hydrofluoric acid and a 30% hydrochloric acid. These are both sold as products. Conversions yield vent air below regulated CFC values, and rapid cooling prevents dioxin formation. The economics of the process were not discussed, but another important market issue has emerged. For CFC replacements made by Hoechst in the future, this secondary recovery technology has allowed them to guarantee that all products will be taken back and recycled or treated chemically. This is an important concept in future sales.

UNIVERSITY OF STUTTGART

Researchers in the Chemical Engineering (Verfahrenstechnik) Department are active in clean technology development. There is substantial industrial support for this effort, and two areas describe the type of projects underway:

- energy conservation, and
- improvement of process and material understanding for use in clean technology applications.

The group leader in this field is **Prof. Gerhard Eigenberger (tel: 49-711-641-2229, fax: 49-711-641-2242)**. Three of their projects are described here to illustrate the kinds of efforts underway at the university.

Low concentrations of organics in different air streams are a leading pollution control issue, and technologies are being developed for meeting new standards. Professor Eigenberger's efforts are to make significant energy efficiency improvements in these unit processes because the resulting utility-related waste reduction is significant. The Stuttgart researchers have developed recycle loop approaches that enhance the chemical potential for organic vapor removal. Starting with an activated carbon wheel device, the quadrants of the circular geometry are rearranged with respect to the flow of contaminated air. Previously, air with organics had flowed through about a 30-degree quadrant of the wheel as it rotated. On the opposite 30-degree quadrant, the carbon was cleaned by steam flow. From simulation research analyzing the respective chemical concentrations, they first led the steam that had stripped organics from a 30-degree quadrant of the carbon wheel to a condenser. This lowered the temperature, and the cooled air was returned to the 30-degree quadrant immediately before the first steam strip area. This cools and raises the organic content of the carbon (from the residual organics in the air passing the condenser). The gradients from carbon to the first-pass steam stream are raised and hence improved carbon regeneration is achieved. Analyzed overall, this research has led to both increased energy efficiency and organic vapor removal from air.

For copper plating applications, one often has a dilute stream of rinse water from the drag-out of a plating bath. The Stuttgart researchers have applied basic process simulation from the electrochemical membrane and ion exchange fields to develop an improved solution leading to metal and acid recovery. By constructing a selective membrane (bipolar) covering of layers of ion exchange resin and then sandwiching these between an anode and cathode, they have been able to significantly enhance the separation of copper into a concentrated solution. After sufficient mass transfer stages, an electroplating-quality copper solution is achieved, while in the other direction a concentrated sulfuric acid solution is produced.

Membranes are increasingly being used in pollution prevention and pollution control applications. Professor Eigenberger has begun a research program to significantly improve membrane properties so that further expansion in use potential will be possible. They are developing skeletons for thin tubular silicone membrane structures that will be tolerant to aggressive organic vapors. Toluene tolerance is being studied, with concentrations over 2,000 ppm. The tolerance of membrane systems to organic vapors and other aggressive conditions is a necessary infrastructure for greater chemical separation to achieve environmental standards.

The university research in clean technologies appears to be well supported, and many graduate students are being trained in this area. Research topics are fairly directed, but they do have a significant opportunity for actual industrial application.

ITALY

NATIONAL AGENCY FOR NEW TECHNOLOGY, ENERGY, AND THE ENVIRONMENT (ENEA)

The Italian government has launched a large capital investment program for the environment. It is expected that about $5.8 billion will be spent, with 25% for solid and hazardous waste management and 50% for wastewater treatment. Within this budget, about 7% is for overall research on the environment. These efforts stem from the in-depth national studies (called State and Perspectives of the Environment in Italy), which occur every two years. These assessments deal with all aspects of regulations, natural resources, environmental media, industry, transport, and population distributions. One of the authors is **Dr. Guido Guidotti**, who also participates in the future planning for Italian governmental environmental efforts (**tel: 39-6-8528-5880, fax: 39-6-8528-5866**).

Clean technologies are defined only in general terms at this stage of the Italian environmental R&D program. Certain industries appear to be the targets for research:

- textiles,
- metal surface treatment, and
- food processing.

In terms of currently defined research activities, there are two general areas of effort. The first is enhanced utilization potential for membrane systems. Emphasis is being given to membrane material characterization and process modeling. Ceramic membrane and nanofiltration projects are in this clean technology area. The ceramic membrane approach is being enhanced by catalytic surfaces to specifically address nitrous oxide and sulfur dioxide removal from flue gas streams.

The second area is photocatalytic treatment of aqueous materials. In this effort, the kinetics and processes are studied. Also anticipating the requirements for recycling, research is undertaken on this topic for membrane and catalyst systems that reach the end of a useful life. These are valuable materials that will increase in volume as environmental applications expand, hence the R&D on reuse is aimed at the future.

In summary, Italian clean technologies efforts are just beginning. Meetings, conferences, and program planning are starting to include pollution prevention R&D. As the research system, with industry input, learns more of the range of clean technology issues, Italian emphasis in this area will expand.

SWITZERLAND

SWISS FEDERAL INSTITUTE OF TECHNOLOGY (ETH)

Pollution prevention research is most often the increased basic understanding of the mechanisms, rates, and processes involved in manufacturing (rather than the development of completely new technologies). The programs at ETH demonstrate Swiss government, Swiss industry, and university commitments to this area of research as a means to competitiveness and clean environment. **Professor Paul Rys (tel: 41-1-256-3120, fax: 41-1-251-8706)** leads a significant group (40-50 graduate students and postdocs) conducting basic process research that has led to definitive application in industry. As in Germany, the Swiss support comes strongly from industry in a more or less directed fashion, however there remains a commitment to publish and to invest in future exploratory research ideas. The three following areas were chosen to illustrate their research.

The formation of secondary products in reactions, whether at recoverable or trace levels, is a recurring limitation to process efficiency or environmental compliance. When Dr. Rys began work in this area, much nonpredictable data in industrial synthesis processes did not conform to kinetic or equilibrium theory for the reactions involved. By introducing the issue of mass transfer in micro fluid packets occurring during the turbulent mixing of a reactor, they began to understand the coupled nature with actual reaction kinetics. By using basic fluid mechanics principles and increasing computing power (now routinely with advanced Cray machines), they have begun to unravel these interactions. In some cases with slow mass transfer due to the mixing regime, secondary products are formed because the first reaction product concentration builds up within these small fluid packets (and undergoes alternate reactions) before the next reactant can arrive to complete the primary reaction sequence. In other cases, energy inputs are increased to enhance the mixing and micro mass transfer. But limits are reached in which this energy is simply dissipated as heat and thus is inefficient. Of great importance, this group is moving toward beginning with specific reactions (described in terms of reaction order and steps) and then, by simulation, developing the geometry of reactor shapes and mixer devices to achieve optimum yields. Some of these shapes are very surprising. Their computing tools for heat transfer, reaction kinetics, and mass transfer are now being applied to the fiber spinning process with the design of the fine pore spinning head.

Natural and synthetic fibers are major products for society. Dyeing to yield many colors often is dependent on centuries-old wet dyeing chemistry. This process yields large amounts of salts from the dye transfer process from solution to fiber (a notoriously inefficient reaction step). Alternatives to improve this efficiency remain unavailable in realistic economic terms, hence Dr. Rys attacked the problem from a different environmental perspective. The current chemistry involves dithionate as an inorganic reducing agent yielding sulfate and salts. These inorganics are difficult to treat in wastewater and usually are discharged. Environmental regulations are becoming severe in this area. They instead began research to find an organic reducing agent, with attractive economics, that could subsequently be treated with greater ease to meet environmental standards. Hydroxy acetone, with ultrasound, was developed. Wastewater treatment is then by anaerobic reactor, to produce a high-quality effluent that can be discharged to municipal treatment plants. Methane is recovered for heating, and the low volume of sludge is used in agriculture. Overall the process is both energy and chemically improved; on a straight economic basis it is 20% less costly. This development promises to be the future direction for textiles and illustrates the concept of substitution of organic for inorganic as an option for cleaner manufacturing.

Energy usage permeates the issues of cleaner production and the use of consumer goods. The Swiss group has also focused attention on solar energy production, again trying to identify novel means to apply basic research to important national needs. One central issue is the cost and limitations of making silicon surfaces for solar photovoltaic conversion. In an innovative strategy, Dr. Rys' group first casts aluminum foil, which is easy to achieve in large dimensions, shapes, and with very high purity. They then use an exchange process (and probably a few novel procedures) to replace as much of the aluminum molecules with silicon as desired, including the full aluminum skeleton. The large silicon foils can then be used for collectors. Although they get a semi-crystalline product, upon heating, a crystalline silicon surface is achieved. This is the highest efficiency form for photovoltaic applications (still only about 10% of solar energy input).

Other ETH professors are involved in recycling demolished building and pavement material; this has become a high priority in Switzerland and Germany. Such material is relatively inert, but it is of significant volume to create concern for long-term landfill capacity. However, successful markets of the same magnitude as the debris supply do not exist. Research at ETH has thus focused on increasing the scientific knowledge related to utilization of such construction and similar waste materials. Basic pavement tests (laboratory and actual pavement tracks) are done with varying fractions of the recycled material along with the normal constituents of paving. Recyclable materials under examination include combustion cinders and concrete materials containing tar and bitumen.

Another ETH clean technology research effort is developing catalyst systems for converting carbon dioxide into usable organics. Copper/zirconia-modified catalysts, with and without promoters, are studied as to surface mechanisms. A synthesis of methanol from carbon dioxide with high selectivity and activity is the intended conversion.

The projects described above illustrate the significant contributions to research in clean technology by the Swiss Federal Institute of Technology. The strong government and industry support reflects both the established university expertise and the interest in pollution prevention by industrial corporations.

UNITED KINGDOM

RESEARCH COUNCILS INITIATIVE ON CLEAN TECHNOLOGIES

The combined efforts of the Science and Engineering Research Council (SERC) and the Agricultural and Food Research Council (AFRC) are focused on a distinct initiative to stimulate research for environmental improvement. Their emphasis on clean technologies searches for ideas that will lead to new processes and products that will inherently forestall pollution and make efficient use of energy and material resources. Toward this end, a Clean Technology Unit was established in 1990 and oversees a three-year budget of about $19 million (**Dr. N. Lawrence, tel: 44-793-411-122, fax: 44-793-411-020**). The aim is to be less "near market" in research investment, with the first priority being new technologies. The second priority is research on existing processes to make these cleaner. The third priority is research on treatment or clean-up concept improvements. The mechanisms of funding require proposals, to first achieve support within standard subject committees or boards. Then the Clean Technology Unit would consider using their specific funding base.

A range of ideas reflecting the very broad interpretation of clean technologies has been developed as a result of the collaborative nature of this initiative. The philosophy and research priorities of AFRC and SERC are thus involved. Three target themes have emerged:

- harnessing photosynthesis,
- clean synthesis of effect chemicals, and
- farming as an engineering process.

An additional topic for funding, but not yet a complete theme, is the sustainable city. This is being developed in conjunction with the Economic and Social Research Council (ESRC). Finally a fourth target theme, provisionally referred to as waste minimization, is currently nearing completion as a working document and funding area. The philosophy of this U.K. effort is to promote meaningful academic research in clean technology that distinguishes between the public trend and fashionable feelings on environmental issues and the best perception of scientific and technological research needs. The following descriptions cover the target themes in regard to general approach and current distribution of actual funded projects.

"Harnessing photosynthesis" is a theme to power biotechnology or to obviate the polluting potential of present industrial or agricultural activities. The current budget in this theme is about $880,000. The potential of research is defined as contributing to clean generation of fine chemicals, feedstocks, raw materials, and fuels. The clean technology initiative has had to carefully avoid already well-funded areas or those in which the U.K. is not near the forefront of academic contributions. As a result, this program focuses on understanding and defining biological limits to the utilization of solar energy. Subjects of priority are

- environmental limitations to energy capture, in which research is sought in processes that determine quantum efficiency (such as adaption and self-repair of photosynthetic apparatus under nonoptimal environments), and in physiological control mechanisms (such as intrinsic resistance to extremes and reactive acquisition of acclimatory tolerance);
- carbon fixation and synthesis of stable products with industrial potential (specifically emphasizing metabolic control of carbon fixation, starch metabolism, lipid metabolism, and novel approaches to photosynthetic feedstocks).

In addition to the above subjects, there is also funding of research to maximize exploitation of solar energy within these biological limits. Subjects of priority are biofuels and chemical feedstocks.

Within the above framework, the Clean Technology program has begun to stimulate research projects into an organizational matrix. The three main subjects and their currently funded research components are:

Harnessing light-capture processes
- structure-function of photosystem II
- molecular dissection of light-response promoters

Exploiting stable chemical products
- oleate desaturation mechanism in oilseeds
- starch metabolism in photosynthetic tissues
- expression of antibodies, chimeric antibodies, and lymphokines in transformed plants

Driving other clean technologies
- PCR-based resolution of genes encoding isozymes expressed during lignocellulose degradation by Phanerochaete chrysosporium.

Clean synthesis of effect chemicals is the second complete theme under the SERC/AFRC Clean Technology program. Current budget for this theme is about $1.25 million. This theme began with a narrow focus on potential contributions of biological catalysts to new compounds. With further debate, the range of investigations now include chemical, biological, and engineering studies related to biologically based syntheses or processes. The assumption is made that such approaches are defined as clean technology.

Seven fields were illustrated as containing the elements for research that would lead to clean technology under the clean synthesis theme. These include

- biosynthesis studies of reaction sequences;
- biosynthesis research on production of chemicals using plant, microbial, or plant culture routes;
- enzymes applied to organic synthesis;
- new enzymes;
- redesigning enzymes;
- novel catalysts; and
- crop production an crop protection.

By integrating these fields of expertise with the commercial and engineering endpoints that appear promising, this theme arrived at operational topics for priority funding. These were as follows, with current actual projects listed for illustration:

Reaction conditions (study of solvent properties)
- no current projects

New biocatalysts
- protein modulation of haem reactivity - horseradish peroxidase as a ligninase
- methylmuconate pathway in actinomycetes

Chemical processes
- enantioselective atom abstraction reactions
- novel methods for homochiral synthesis
- ordered adsorbed states in bicyclic aromatics - relation to metal catalyzed chiral synthesis
- detachable ionic groups and the use in novel polymers

Separation processes
- catalytic upgrading of biomass and waste-derived pyrolytic oils

Substitution (clean) products
- no current projects.

Farming as an engineering process is the third complete theme for clean technology research. Current budgets for this theme are about $930,000. This grew from observations that farming and the utilization of food products are intertwined and that environmental impacts are obvious. The very widespread character of agriculture means that prevention approaches are important for environmental improvement. Agriculture does have much empirical information; this new initiative sought to bring a process engineering approach so that a cleaner technology for food and farming would be possible. The basis for this new approach is to divide the agricultural system into subprocesses. These are

Plant production
- photosynthesis and growth
- nutrient utilization
- weed and pest control

Animal production from plants
- preservation of plant material
- feed conversion
- protection of animal health and welfare
- fish production

Food and industrial feedstocks from plants
- separation of components
- storage
- processing
- production of fine chemicals and pharmaceuticals

Food and industrial feedstocks from animals
- rendering
- meat, leather, and wool processing.

The plan calls for research to improve understanding of these subprocesses and the mechanistic interactions among these. The current agenda contains the following:

Plant production
- culicoides control, a pheromonal approach
- transport of agricultural spray droplets in turbulent air flows
- modeling herbicide interaction with photosynthetic reaction centers
- influence of soil organic constituents on retention and transport of synthetic organic chemicals
- water and solute movement in aggregated soils
- molecular biology of aerobic and anaerobic denitrification pathways for the loss of nitrates
- spatial and temporal controls of denitrification in permanent pasture

Animal production from plants
- no current projects

Food and industrial feedstocks from plants
- heat and moisture transfer in the ambient cooling of grains for reduced pesticide use

Food and industrial feedstocks from animals
- no current projects.

Even with similar relative importance to clean technology, it is clear that the research response is uneven among these topics, reflecting classical academic interests.

An important dimension of clean technology is contained in the theme of a "sustainable city." Although not a complete theme, this area of research has the largest number of projects (20) and a current budget of about $1.8 million. Most of these research efforts are in improving traffic, in lowering air emissions, or in alternate power transportation.

Emerging as the fourth complete theme under clean technology is "waste minimization." The goal is to embrace all manufacturing as fields for research along a common theme. That is, to develop any technique, process, or activity that either avoids, eliminates, or reduces waste at the source, usually within the confines of a production unit, or allows reuse or recycling of the waste for benign purposes. At this stage, no specific projects are funded and so only estimated areas and budget percentages are available. It is proposed to fund the categories:

- methodologies determining environmental improvement (20%)
- cleaner products (25%)
- cleaner processes (30%)
- cleaner waste treatment (25%).

Again, the proposals that clear the standard committee reviews will determine the actual distributions.

The remainder of the current clean technology budget is in areas not covered under conventional U.S. pollution prevention concepts, and so only the topic areas are listed here:

- treatment of dilute wastes (about $3.3 million)
- analysis and measurements (about $1.1 million)

- treatment in combustion processes (about $2.4 million).

Research Councils Summary

The Research Councils have made a reasoned and significant investment in research for clean technology in the U.K. The program places considerable emphasis on research and the initiatives of the academic community. Industrial input was principally in defining the broad topics within each clean technology theme. The significant funding in topics not aimed at prevention reflects the considerable risk involved in launching new proposals by individual university engineers and scientists. Having to clear traditional hurdles of research quality through the existing subject committees (that are focused on many issues not related to clean technology or environment) is difficult. Hence traditional areas of research are favored, and academic investment in undertaking new research concepts for this emerging theme are risky.

DEPARTMENT OF TRADE AND INDUSTRY/THE HUB TECHNOLOGIES

Clean technology R&D is also undertaken by the Department of Trade and Industry (DTI), with assistance from the Department of the Environment. At the DTI, **Douglas Robinson (tel. 44-71-215-1027, fax: 44-71-215-2909)** has organized the clean technology initiative, assisted by **Dr. David Pounder (tel: 44-71-276-8310, fax: 44-71-276-8333)** of the Department of Environment. This effort began with a study to evaluate long-term issues for manufacturing and environmental improvements. The goals of this study were to:

- Identify the most significant environmental problems facing sectors of major U.K. industry
  chemicals
  agrochemicals
  metal manufacturing
  metal finishing
  electrical and electronic products
  textiles
  food
  leather
  pulp and paper
  nonmetallic minerals
  waste incineration
- Evaluate work currently being undertaken by industry and universities
- Identify areas of cleaner technology having the potential for development by industry and/or the scientific community for use in next-generation processes in responding to initiatives for cleaner technology.

These areas of cleaner technology are referred to as "Hub Technologies." In the search for hub technologies, processes—not products—became the focus of attention. The methodology for identification was the use of industry experts to make a series of judgments on wastes and processes, with weighting factors to establish priorities. This proved to be a qualitative approach, even though numerical graphs were produced.

A hub technology had to meet several criteria. First, such a technology had to have already been proven at the level of basic science. Second, a hub designation was reserved for approaches that were applicable to more than one of the industry categories. These criteria seemed to be easily met by more general areas of technology. The resulting hub technologies were:

- process flow sheeting
- process control software
- reactor engineering
- membrane processing
- super- and sub-critical fluids
- photo(electro)chemistry
- ultrasonics and sonoelectrochemistry
- ohmic processes
- induction heating.

These hub technologies appeared to have evolved from specific instances of potential application, rather than to have been generated as generic de novo concepts.

The DTI-sponsored study also contained several independent observations. This report was made after the U.K. Integrated Pollution Control Act was established as law; it required that discharges to all media be aggregated for regulatory evaluation. The authors (of the law) noted that with 1-4 years for initiation of enforcement, pollution control not prevention is highly favored. Basically we appear to underestimate the time needed to undertake significant fundamental process change for large-scale manufacturing. The authors also observed the "ratchet effect" of regulation. In this phenomenon, regulatory agencies use progress, even if voluntary, to force industry compliance without regard to the magnitude of environmental benefits or significance. This ratchet effect has had a chilling impact on the advancement of cleaner technology.

The next phase for DTI is to hold in-depth conferences on each hub technology. The goal is to develop research and development needs that can then be acted on with DTI funding. The LINK program of 1:1 matching of industry and government resources will be used. Overall this was a very proactive move, with a clear objective to better define for researchers the clean technology agenda. Projects emerging should, if successful, be more easily moved into the manufacturing arena because of this DTI program.

CONCLUDING OBSERVATIONS

There is a large funding base for clean technology in Europe. From the eight organizations reviewed, estimated annual resources in this field are $70 million. There is a strong emphasis on investment to add knowledge that will improve the probability of clean technology as an environmental solution. There is also an emphasis on technology transfer and the overall industrial improvement in competitiveness and the environment. Both processes and products are considered valid targets for research and government expenditures. The definition of clean technology is wide, but the existence of ample resources allows this wider portfolio of R&D.

Recurring topics appear among the diverse funding agencies and research establishments. A dominant characteristic of these topics appears to be the origin of the research focus within a given industry or specific process. This origin identifies the environmental challenge, while the R&D incrementally creates improvements or new innovative approaches not previously considered. Five topics were found to have significant critical mass across these European countries:

- plastics and polymer recycling and greater environmentally friendly properties;
- expansion of product and process potential for renewable chemicals or materials;
- recycle of a steadily wider dimension of chemicals, materials, or products through targeted R&D;
- carbon dioxide utilization; and
- reduced chemical use in favor of natural approaches.

Clearly many other smaller, more focused efforts may also expand with the success of research efforts or with shifts in industrial priorities. The cataloguing of such individual efforts in this report is thus to allow further contact by the reader. The European clean technology program overall is exciting at a scientific level—ranging from incremental improvements to searches for substantially different approaches. Continued tracking of results and future R&D efforts will be important for ensuring the most effective use of U.S. resources in this area.

Chemistry

Testing for Drug Use via Hair Analysis

by David A. Kidwell. Dr. Kidwell is a research scientist in the Chemistry Division at the Naval Research Laboratory, Washington, D.C. He has been involved in developing technology to screen for drugs of abuse in a number of matrices for the past 10 years.

KEYWORDS: hair analysis; cocaine; heroin; urinalysis; mechanism of incorporation

INTRODUCTION

The First International Meeting on Hair Analysis as a Diagnostic Tool for Drugs of Abuse Investigations was held in Genoa, Italy, 10-11 December 1992. This conference was organized under the auspices of the Istituto Superiore di Sanita', Italy, the International Association of Forensic Toxicologists, the United Nations Interregional Crime and Justice Research Institute, and the Ospedale Niguarda Ca'Granda, Milano, Italy. Papers from this meeting will appear as a special edition of *Forensic Sciences International* in the fall of 1993. During this two-day meeting, 39 papers and oral communications were presented. To help the reader better understand my impressions of this meeting, a brief history of hair analysis for drugs of abuse and the Navy's interest in this technology is warranted.

For the past several years, the Department of Defense (DoD) has placed increased emphasis on detection and deterrence of drug abuse. The use of urinalysis as a deterrent for drug use is one of the key components of this emphasis. The Navy, as a component of DoD, has been a strong proponent of urinalysis and as such is probably the world's largest drug screening organization. Because emphasis was placed on the urinalysis program, the self-reported use rate in the Navy dropped from 33 percent to less than 4 percent in the past five years. A recent survey of substance abuse in the military found that 76 percent of this population believe that urinalysis testing has reduced drug abuse in the military.[1]

However, despite the programmatic success of the Navy, there is always room for improvement. For example, the short (2-4 day) half-life in urine of many drugs of abuse makes detection of infrequent drug use difficult.[2] An individual could easily abuse cocaine, amphetamines, or heroin (the three drugs with the fastest increase in abuse in the population) over the weekend and not be detected the following Monday. About five years ago, we became interested in hair analysis as an adjunct to urinalysis because of reports that had appeared in the literature[3-6] and reviewed elsewhere.[7] We foresaw that one application of hair analysis might be to support or refute an individual's testimony at an administrative hearing or trial. Hair analysis also may provide a long-term usage history that will improve post-treatment monitoring. If proven in practice, hair analysis could eventually replace urinalysis.

Hair analysis was presented as a technique that was able to determine use, approximate amount of use, and frequency of use over a time span of months to years.[8] This prospect would nicely complement the Navy urinalysis program. However before hair analysis could be used, several problems needed to be resolved and several important questions needed to be answered. For example:

- What is the sensitivity of hair analysis?
- Could a single use of drugs be detected?
- What if the results of urinalysis and hair analysis disagreed?
- What confirmation technology is appropriate?
- What are the mechanisms of incorporation, retention, and loss of drugs of abuse?
- Can passive exposure be confused with active use?

We began a research program to address these questions, and some of our research results were presented at this meeting and elsewhere.[9-11] The complexity of hair analysis and the issues involved in applying the technique by the forensic community were important topics at this meeting. Some of my impressions of this meeting and the significant findings are presented below. It must be kept in mind that, at the present time, hair analysis is not a sufficiently proven technology for use in the DoD.

SIGNIFICANT TALKS AND MY IMPRESSIONS OF THE CONFERENCE

The driving force for the application of hair analysis in Italy was discussed by a number of the Italian speakers such as A. Fiori (Catholic University of Rome, Italy). Two years ago, a new Italian law was passed that mandated evaluation of the severity of addiction of an individual who had been arrested for a drug possession offense. Apparently Italy, like the U.S., has two broad classes of drug offenses: simple possession and distribution. In Italy, the penalties for distribution of drugs can be quite severe, whereas for simple possession there may be no penalty, mandatory treatment, or incarceration. The revised law changed how the evidence of a crime was to be considered. Currently, a charge of simple possession can result when the quantity of drug in an individual's possession was a thirty-day or less supply for that individual. For some drugs, such as cocaine, the dosage varies widely. A heavy user may have a 1-10 g/day habit, whereas casual users may only use 100 mg/week (a 1-2 dose/week use). Therefore, an individual could have in his possession a wide range of amounts—from 400 mg to 300 g of cocaine for personal use.

Contrast this to a low-level drug distributor who would not have in his possession more than a few grams of cocaine. Thus, how to properly classify an individual as a distributor of cocaine or as just a heavy user needing intervention treatment, is currently very problematical in Italy. In contrast, the U.S. sets strict amounts above which an individual can be charged as a distributor rather than with simple possession. Current Italian methodology looks at a number of very imprecise factors in determining use, such as:

- the severity of withdrawal symptoms, which vary greatly among individuals and drug type;
- concentration of drugs found in urine or blood, which would vary depending on the length of time since the use had occurred and the amount consumed; and
- the presence of needle marks or other physical signs of drug use, which would be absent in many crack cocaine users.

Hair analysis has the promise of measuring use history and gaining some insight into the amounts ingested. It appeared very promising to many of the Italian speakers as a technique that could remove some of the variables mentioned above.

M. Möller [University of the Saarland, Homburg, Federal Republic of Germany (FRG)] presented interesting talks on his use of hair analysis in certain forensic cases, dealing primarily with opiates (morphine, heroin, and codeine). Doctor Möller mentioned several overdose cases where he used hair analysis to either demonstrate that the victim was a long-time user of heroin or a non-user of the drug. Therefore, he could propose that the victim died as a result of an accidental overdose (hair showed long-term use) or murder (hair showed no, or only short-term use) of the drug. He also discussed his enzymatic dissolution technique for hair that allows 6-monoacetylmorphine (6-MAM, a heroin metabolite) to survive the analytical procedure. His results indicate that there is a higher concentration of 6-MAM than morphine in hair, completely opposite to what is found in urine. These results may indicate that the mechanism of drug incorporation into hair is not through the bloodstream.

Y. Nakahara (National Institute of Hygienic Sciences, Tokyo, Japan) discussed his results with controlled experiments on administering amphetamine surrogates to humans.[12] He found a good correlation between the amount of drug administered and the amount found in the hair. However, he also showed that the material was not stable in the hair. Approximately half of the drug was lost over a 5-6 month period.

L. Potsch (Johannes Gutenberg-Universität Mainz, FRG) discussed some of his published research[13] in animals. This research showed fluorescent banding of the fur when the animal was injected with fluorescein as a drug surrogate. He also noted that the bands produced were twice the width expected, based on the growth rate of the fur and the lifetime of the fluorescein in the animal. This could imply a mixed mechanism for incorporation of this dye. However, if an ion exchange mechanism is responsible for the incorporation of drugs into human hair, anionic fluorescein is a poor surrogate for drugs of abuse. Because most drugs are cationic, they would bind to different sites than would fluorescein.

In contrast to these two papers, which indicated some dose-response correlation, G. Henderson and M. Harkey (University of California at Davis, U.S.) presented data on controlled administration of labeled cocaine to humans. This research showed no correlation to the amounts of cocaine administered and the amounts found in the hair. They also could find no correlation between the plasma, urine, or saliva levels and the amounts of metabolites or drug found in the hair. They theorized that the amounts and patterns of metabolites best fit that found in sweat and suggested that sweat or other sweat-like secretions were the main mechanism for drug incorporation into hair. This is in contrast to entrapment of drugs from the blood stream, as had been suggested by others. The mechanism of drug incorporation is a very important issue that is often neglected. If the main mechanism for incorporation is sweat and because sweat enters from the outside, then NO means could ever be developed to distinguish passive exposure from active use. Some of their analytical methodology has been published.[14]

G. Henderson also discussed an interesting experiment that they had conducted. They asked several individuals, after administration of labeled cocaine, to hold negative hair in their hands. Both these hair specimens and the users' hair were tested. Usually, more drug was found in the negative hair that was contaminated by the sweat of the users than was found in the users' hair. This elegant study underscored the great potential hair has for incorporating materials from the external environment. Some anecdotal details were also given that drugs may be more frequently found in black hair than in brown, but Dr. Henderson did not have enough samples to make a firm conclusion.

Likewise, E. Cone (NIDA Research Addiction Center, Baltimore, U.S.) discussed some previously published data[15] on metabolites of cocaine found in hair and the lack of correlation between dose and amounts that he has observed in his experiments on controlled dose studies in humans. He also presented a study showing the potential for passive exposure. Three known non-drugs users were exposed to the vapors from crack cocaine smoke. They were then asked to treat their hair with their normal hygienic procedures. The hair was analyzed over a period of several weeks. Cocaine was present even after eight days of normal hair washing. Doctor Cone soaked hair in various drug solutions and found that the incorporated drug was difficult to remove.

In contrast to our soaking data, he found that 10 shampooings could remove the drug. Although Dr. Cone had dissolved hair in other studies[16] on opiates, he used hydrochloric acid (HCl) extraction in this study. His analytical methodology may be insensitive to small amounts of drugs because we showed that HCl is inefficient in removing all the drug from the hair. Dissolution of the hair has also been shown to be necessary by others.[21] In addition, Dr. Cone presented evidence that more drugs are found in black than in white hair. But like the Henderson and Harkey talks, Dr. Cone did not have enough samples to make a firm statement as to whether hair analysis may be biased to hair type or color.

T. Uematsu (University of Hamamatsu, Hamamatsu, Japan) showed a difference in incorporation of nicotine from smokers by as much as ten times lower levels of nicotine in white hair compared to black hair on the same individual. He carefully took into account the different rates of hair growth that could account for some of these striking differences, so that this major criticism would not apply to his results. However, it is not known if his results would also pertain to drugs of abuse. He has authored a number of papers detailing the deposition of haloperidol in hair.[17-20]

W. Baumgartner (Psychemedics Corporation, Santa Monica, CA, U.S.) described his analytical methods.[21] He discussed his kinetic washout procedures (based on the rate of removal of drugs from the hair during the decontamination process) to distinguish active from passive exposure. He underscored the need to dissolve the hair before applying his procedures and before measuring the concentration of drug in the hair. However, he did not discuss what would happen if the hair were not dissolved before the extraction of the drug. In this case, only part of the drug would be recovered.

And then, it would be much more likely that that sample would be considered negative or contaminated under Dr. Baumgartner's kinetic criteria than it would be to designate that sample positive.

D. Blank (Department of the Navy, Washington, D.C.) and I discussed the results of our experiments on passive exposure. We soaked hair under a number of different conditions in solutions of drugs containing radioactive tracers. We followed the kinetics of removal of the drug from these externally contaminated hair specimens by examining the radioactivity in every wash solution during the decontamination procedure proposed by Dr. Baumgartner.[21] In almost every case, we were not able to determine that these samples were contaminated by the kinetic criteria proposed by Dr. Baumgartner.

In other experiments, we tested the extraction procedure often used in the literature to remove the drug for analysis. Our experiments indicated that the normal extraction procedures with HCl did not remove all the drug from the hair and the amounts removed varied with the type of hair and the drug extracted. For example in black hair, even a 42-hour extraction with HCl (2-4 times the normal time found in the literature[22]) removed only 53 percent of the cocaine and less than 25 percent of the benzoylecgonine incorporated by a limited soaking. This underscores the need to dissolve the hair, if an accurate measure of the amount of drug is sought.

Finally, our data are inconstant with simple trapping in the hairs pores or matrix and support an ion exchange mechanism for binding of the drugs to hair. This mechanism is also supported by the binding of cationic species to keratin through ion exchange mechanisms, which is well known in the cosmetics industry.[23] Thus we confirm our previously postulated hypothesis that drugs bind to hair by an ion exchange mechanism rather than by entrapment.[10]

In my talk, I showed data indicating that cocaine could decompose in hair to metabolites, therefore most metabolites would not be a good marker of drug use. I also discussed the fact that sweat contains enzymes (esterases) that are the same as those responsible for production of the metabolites in the bloodstream. These may degrade cocaine in the sweat to a pattern of metabolites that may mimic use. I stressed the difficulties of using tandem mass spectrometry for forensic purposes[24] rather than research purposes[8] because false positives could occur if it is inappropriately applied.

C. Staub (University of Geneva, Switzerland) described an interesting case, still under investigation, where a mother brought into the hospital emergency room a 2-year-old child who she claimed was suffering from a codeine overdose. The child was treated and the usual blood and urine samples taken. Analysis of these specimens clearly indicated that the child suffered from an overdose of heroin. The child was separated from the mother for at least three months while an investigation was undertaken. During this time, hair samples were taken from the child and the mother. Sections analysis of the hair showed that the child's hair was positive in the time under the mother's care and declining in amount during the three month's when the child was separated from the mother. The conclusion was that the child suffered from a heroin overdose and that he had been given heroin in constant amounts for a long period of time, presumably to keep him from crying. The mother's hair showed little heroin use. Later it was discovered that the boyfriend was a long-time heroin user and that she could have obtained the heroin from him. [Another explanation could be that the child may have been exposed to heroin through accidental ingestion of traces of the drug in the home from placing objects in his mouth and that this resulted in the overdose. Whereas, the hair may have been contaminated and from the same environmental exposure. Author] Resolving the issues of passive exposure for hair analysis would be crucial to this case because this was the main measure of "long-term administration" of the heroin. The legal charges against the mother may be significantly less severe if the overdose were accidental rather than if she had intentionally administered the drug.

M. Welch (National Institute of Standards, Gaithersburg, MD, U.S.) discussed his difficulties in preparing standards of cocaine in hair.[25] He soaked hair primarily in dimethylsulfoxide solutions to incorporate the drug. He observed that material could still be incorporated, even after several days of soaking. These prepared samples were sent to a number of laboratories in a round-robin test to compare their analytical procedures.

Several mistakes were noted in the results where drugs were found in negative hair samples. Concerns were raised by the audience in testing these standards in that the standards did not behave as do normal drug user's hair. An appeal was made by Dr. Welch to obtain genuine user's hair for use as standards in future round-robin tests.

Comparing different types of hair on the same body, P. Mangin (University L. Pasteur, Strasbourg, France) showed large variations in concentration between hair types, with pubic hair showing the highest concentration, then head hair, and finally auxiliary hair. In two separate talks, Dr. Offidani (University Cattolica S. Cuore, Rome, Italy) presented similar data for morphine, cocaine, and benzodiazapams and discussed his enzymatic procedure for dissolving hair.[26] However, if passive exposure were a concern (from solutions of drugs), pubic hair is the one type of hair most likely to become contaminated (by drugs in the urine) and therefore would be expected to have the largest amounts of drug. Neither Dr. Mangin nor Dr. Offidani addressed this issue.

T. Mieczkowski (University of South Florida, U.S.) tried to address concerns of racial bias in hair testing by comparing the detection frequency of hair testing in a large number of individuals arrested in south Florida.[27] His results indicated that hair testing gave the same frequency of results across racial lines as would be expected from either self-reported use or urinalysis. He therefore concluded that hair analysis was not racially biased. However, in my opinion his study is fundamentally flawed. Hair analysis frequently detects more drug use than either self-reports or urinalysis. Where there is disagreement between the three measures of drug use, Dr. Mieczkowski assumes that the hair test result is correct. The urinalysis results may disagree with the hair results because the urinalysis test was outside of the 2-4 day window of detection. However, he also dismisses the self-reports as inaccurate reporting by the individuals. He based his arguments on a statistical analysis that a similar number of self-reports are incorrect for urinalysis as are incorrect for hair analysis. By dismissing self-reports that disagree with the hair testing results, one cannot address the greatest concern in hair testing, false positives. A better analysis would be to compare the results where all three measures of drug use agree.

C. Brewer (The Stapleford Centre, London, U.K.) discussed the use of hair analysis from a clinical perspective. His use was in methadone maintenance clinics to assure that the clients are not using heroin and are taking their methadone. He compared urinalysis with hair analysis and found the latter easier to administer, less likely to be evaded, and detected more users. Doctor Brewer cited several cases where users, faced with the prospect of a hair test that was described to them as highly reliable and could detect usage over a long time, either confessed to use or confessed after being presented with the results of the test. He highly recommends hair testing from a pragmatic standpoint of, at a minimum, coercing users into being honest about their drug rehabilitation treatment.

Another meeting (in a similar but expanded format) is planned for June 1994, at the same location. Hopefully by then some of the pressing issues of racial bias, passive exposure, and dose-response results will be better understood.

CONCLUSIONS

Commercial concerns, clinicians, and several forensic scientists are using hair analysis and pressing for widespread adoption of this technique. I left this meeting with the impression that hair analysis is likely to be widely adopted in Italy to meet the demands of their new drug laws to assess a user's addiction. Note that in the case for use of hair analysis by the Italian forensic community, contamination issues would tend to exonerate an individual; hair analysis, as likely used in the U.S., would tend to falsely accuse an individual. Other forensic scientists at the meeting were urging caution until the issues of passive exposure, racial bias, mechanism of drug incorporation, and dose-response results are better understood. Whether or not pressure will be put on the U.S. forensic community to use this technique depends on how widespread the issues raised above are known and understood.

REFERENCES

1. R.M. Biay, M.E. Marsden, L.L. Guess, S.C. Wheeless, V. G. Iannacchione, and S. R. Keesling, *1988 Worldwide Survey of Substance*

Abuse and Health Behaviors Among Military Personnel, Research Triangle Institute, RTI 4000/06-02FR, December 1988, and personnel communication from the Department of Navy.

2. Richard Hawks and C. Nora Chiang, eds., *Urine Testing for Drugs of Abuse* (National Institute on Drug Abuse, Research Monograph Series 73, 5600 Fishers Lane, Rockville, MD, 1986).

3. A. M. Baumgartner, P. F. Jones, C. T. Black, and W. H. Blahd, "Radioimmunoassay of Cocaine in Hair: Concise Communication," *J. Nuclear Medicine* **23** 790-792 (1982).

4. A. M. Baumgartner, P. F. Johns, and C. T. Black, "Detection of Phencyclidine in Hair," *J. Forensic Sciences* **26**, 576-581 (1981).

5. M. Marigo, F. Tagliaro, C. Polesi, S. Lafisca, and C. Neri, "Determination of Morphine in the Hair of Heroin Addicts by High Performance Liquid Chromatography with Fluorimetric Detection," *J. Analytical Toxicology* **10**, 158-161 (1986).

6. F.P. Smith and R. H. Liu, "Detection of Cocaine Metabolite in Perspiration Stain, Menstrual Bloodstain and Hair," *J. Forensic Sciences* **31**, 1269-1273 (1986).

7. M.R. Harkey and G.L. Henderson, "Hair Analysis for Drugs of Abuse," *Advances in Analytical Toxicology* **2**, 298-329 (1989).

8. W.A. Baumgartner, V.A. Hill, and W.H. Blahd, "Hair Analysis for Drugs of Abuse," *J. Forensic Sciences* **34**, 1433-1453 (1989).

9. D. A. Kidwell, "Analysis of Drugs of Abuse in Hair by Tandem Mass Spectrometry,' presented at the 36th American Society of Mass Spectrometry Conference on Mass Spectrometry and Allied Topics, San Francisco, CA, June 6-10, 1988.

10. D.A. Kidwell and D.L. Blank, "Deposition of Drugs of Abuse into Human Hair," Society of Forensic Toxicology Conference on Hair Analysis, May 26, 1990.

11. D.A. Kidwell and D.L. Blank, "Hair Analysis: Techniques and Potential Problems," in *Recent Developments in Therapeutic Drug Monitoring and Clinical Toxicology*, Irving Sunshine, ed. (Marcel Dekker, Inc., New York, 1992), pp. 555-563.

12. Y. Nakahara, M. Shimamine, and K. Takahashi, "Hair Analysis for Drugs of Abuse. III. Movement and Stability of Methoxyphenamine (As a Model Compound of Methamphetamine) Along Hair Shaft with Hair Growth," *J. Analytical Toxicology* **16**, 253-257 (1992).

13. L. Potsch and H. Leithoff, "Fluoreszenzmikroskopische Untersuchungen zum Einbau von Fluorescein in Haare," *Rechtsmedizin* **3**, 14-18 (1992).

14. G.L. Henderson, M.R. Harkey, C. Zhou, and R.T. Jones, "Cocaine and Metabolite Concentrations in the Hair of South American Coca Chewers," *J. Analytical Toxicology* **16**, 199-201 (1992).

15. E.J. Cone, D. Yousefnejad, W.D. Darwin and T. Maguire, "Testing Human Hair for Drugs of Abuse. II. Identification of Unique Cocaine Metabolites in Hair of Drug Abusers and Evaluation of Decontamination Procedures," *J. Analytical Toxicology* **15**, 250-255 (1991).

16. E.J. Cone, "Testing Human Hair for Drugs of Abuse. I. Individual Dose and Time Profiles of Morphine and Codeine in Plasma, Saliva, Urine, and Beard Compared to Drug-Induced Effects on Pupils and Behavior," *J. Analytical Toxicology* **14**, 1-7 (1990).

17. T. Uematsu, R. Sato, K. Suzuki, S. Yamagucii, and M. Nakashima, "Human Scalp Hair as Evidence of Individual Dosage History of Haloperidol: Method and Retrospective Study," *European J. Clinical Pharmacology* **37**, 239-244 (1989).

18. R. Sato, T. Uematsu, R. Sato, S. Yamaguchi,l and M. Nakashima, "Human Scalp Hair as Evidence of Individual Dosage History of Haloperidol: Prospective Study," *Therapeutic Drug Monitoring* **11**, 686-691 (1989).

19. T. Uematsu, R. Sato, 0. Fujimori, and M. Nakashima, "Human Scalp Hair as Evidence of Individual Dosage History of Haloperidol: A Possible Linkage of Haloperidol Excretion into Hair with Hair Pigment," *Archives Dermatol. Research* **282**, 120-125(1990).

20. H. Matsuno, T. Uematsu, and M. Nakashima, "The Measurement of Haloperidol and Reduced Haloperidol in Hair as an Index of Dosage History," *British J. Clinical Pharmacology* **29** 187-194(1990).

21. W. Baumgartner and V. Hill, "Hair Analysis for Drugs of Abuse: Decontamination Issues," in *Recent Developments in Therapeutic Drug Monitoring and Clinical Toxicology*, Irving Sunshine, ed. (Marcel Dekker, Inc., New York, 1992), pp. 577-597.

22. D. Fritch, Y. Groce, and F. Rieders, "Cocaine and Some of Its Products in Hair by RIA and GC/MS," *J. Analytical Toxicology* **16**, 112-114 (1992).23.

23. E.D. Goddard, "Substantivity Through Cationic Substitution," *Cosmetics and Toiletries* **102**, 71-80 (1987).

24. R. M. Martz, "The Identification of Cocaine in hair by GC/MS and MS/MS," *Crime Laboratory Digest* **15**, 67-73 (1988).

25. C.C. Allgood, L.T. Sniegoski, and M.J. Welch, "Determination of Drugs of Abuse in Hair by GC/MS," presented at the 38th American Society of Mass Spectrometry Conference on Mass Spectrometry and Allied Topics, Tucson, AZ, June 3-8, 1990.

26. C. Offidani, A. Carnevale, and M. Chiarotti, "Drugs in Hair: A New Extraction Procedure," *Forensic Sciences International* **4**, 35-39 (1989).

27. T. Mieczkowski, J. Barzelay, B. Gropper, and E. Wish, "Concordance of Three Measures of Cocaine Use in an Arrestee Population: Hair, Urine, and Self-Report," *J. Psychoactive Drugs* **23**, 241-249 (1991).

Computer Science

Virtual Reality in the U.K.—Three Diverse Applications

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KEYWORDS: virtual reality; telepresence; force feedback devices; interactive hardware; software systems

INTRODUCTION

Virtual Reality! Rarely has the human imagination been so entranced by a technology. The very idea of entering computer-generated space with a reality of its own is enthralling to many—and frightening to some. Yet the short- and long-term usefulness of the technology is clear. Applications include training, simulation, concurrent engineering, telecommunications, telepresence, scientific visualization, education, and entertainment. And, I suppose, our list should include the infamous term for that far-into-the-future application asked about at every virtual reality press conference—teledildonics (i.e., virtual sex).[1]

What is virtual reality—and its pseudonyms and near partners of virtual environments, virtual worlds, synthetic environments, etc.? No uniform definition for these terms, or for differences between them, has yet emerged. Yet most would agree that virtual reality (but not synthetic environments) has two required components:

- three-dimensional (3-D) data immersion, and
- an interactive capability.

This still leaves plenty of room for debate. For example, all would agree that head-mounted, stereo displays provide immersive 3-D. But what about a surround screen? (Most would accept this). Or is stereoscopic display on a workstation terminal included? (Most would say no, this is computer graphics but it does not fall within the virtual reality interface paradyne). Even without a uniformly accepted definition, these remarks should provide guidance as to which of the many commercial products using the term *virtual reality* to describe themselves really fit the bill!

Thus, virtual reality is just another way of interfacing to the computer. The reality presented may be computer-generated, real, or a synthesis of both. Virtual reality's strength is that it is the right way to interface for those applications where 3-D, immersion, and interactivity are all required. The current interest is driven by affordabilty. Flight simulators have provided users with virtual reality for decades, but they have cost millions of dollars each. Today, a high-end graphics workstation and a set of peripherals for virtual reality can be purchased for approximately $250,000. This is not inexpensive, but it represents an affordable price for many organizations if the need can be justified. And, as we shall see, worthwhile virtual reality can be performed for even less.

This article examines three British companies with diverse applications and research interests. Advanced Robotics Research Ltd. of Salford (near Manchester) seeks to develop a telepresence testbed, with special emphasis on the ability to consider the human factors elements. Current efforts are in two parts: the virtual reality interface for telerobotics, and scene reconstruction using a laser ranging device. W Industries Ltd. of Leicester is producing virtual reality products for the entertainment market. They have marketed several commercially successful products. We will examine the techniques and limitations of inexpensive, "low" end virtual reality systems for the entertainment industry. Finally, Division Ltd. of Bristol offers a modularized software development system, as well as hardware, for developers of virtual reality applications. Their systems are being used in several leading European applications.

THE ADVANCED ROBOTICS RESEARCH LABORATORY

Advanced Robotics Research Limited (ARRL) was formed in 1988 to manage a new U.K. National Advanced Robotics Research Center, as part of the U.K. Department of Trade and Industry's (DTI) 1985 Advanced Robotics Initiative. ARRL is located on the campus of Salford University, near Manchester, U.K. The Center was granted £5 million U.K. ($7.5 million U.S.) in start-up funds to be spread over 5 years. It is constituted as a commercial enterprise and expected to proceed independent of government funding.

Virtual Reality Hardware and Software at ARRL

The computing (and indeed the research) is divided into two parts. On the virtual reality end,[2] ARRL uses Division Limited's SuperVision (see below). ARRL was the first purchaser of a Division Limited Vision system, recently upgraded to SuperVision. Several devices input to SuperVision. These include voice input via Marconi Marcospeak and the Ascension "Bird" electromagnetic sensor for head tracking. ARRL has recently obtained both a new Polhemus head tracker and the new Ascension "Big Bird" tracker that extends range to an 8-foot operating cube (3 feet has been standard for trackers). This will allow comparison between the Polhemus (an AC device) and the Ascension (a DC device).

I was disappointed not to be able to try ARRL's tactile feedback AirGlove data glove. It had been damaged in a recent show and was undergoing repairs. The AirGlove concept was developed by Jim Hennequin of Airmuscle Ltd.

(Cranfield, U.K.) and Robert Stone (ARRL) for use in conjunction with a VPL DataGlove. It provided pneumatic-based force feedback to the user. There appears to have been a divergence in approach between Hennequin and ARRL, and Stone is now developing a handgrip device that incorporates an IsoTrak or Bird sensor. Force feedback is provided by expanding the grip slightly, using three to five air pockets designed for that purpose. A VPL headset was used for my demonstration; a LEEP headset was also available. The LEEP, according to Stone, provides better resolution (around 300 by 400 pixels), but it requires use of a body pack and is hard to calibrate. Thus, it is not used for demonstrations.

ARRL had developed several demonstrations, both the usual architectural fly-through of a building and a scientific-visualization-oriented one to examine a synthetic surface. Improving virtual reality, according to Stone, requires more computing power for better rendering, better resolution, and contrast in the LCD displays in the head-mounted unit. Other needs are the reliability and calibration difficulties of the data gloves and generating a better human/computer interface (HCI) understanding of human requirements for interfacing to virtual worlds.

Robotic Sensors and Software

The remaining hardware and software efforts focus on robotics for telepresence. The goal is to be able to recreate 3-D scenes from non-optical sensors so that virtual reality can then be used for remote user-based manipulation. Work on path planning and obstacle avoidance is also performed.

The 3-D image analysis system uses a scanning laser rangefinder as an input sensor. ARRL owns an imaging head, built by NEL of Scotland, that operates over a 1-5 meter range and acquires an 8-bit range image in 2 seconds. A semiconductor laser produces a vertical strip of infrared light, which is reflected by a scanning mirror. A slightly offset CCD (charge-coupled device) camera also views the scene. When the laser strikes the scene, the camera detects a stripe containing distortions due to objects. By scanning the mirror, a complete image is obtained. A transputer-based computer system hosted by a Sun Sparc Workstation processes the image data and communicates with the SuperVision system. The processing reduces the rangefinder output to 3-D coordinates and uses machine vision methods to segment the results into planar parts. This representation is then made format-compatible with the SuperVision system. Obstacle avoidance algorithms are also being developed. These involve rule-based mobile path planners.

Navigation displays are similar to those I have seen for underwater autonomous vehicles. The ARRL algorithms use probabilistic methods to correct constantly upgraded estimates of position. The track is shown at intervals, and the accumulated errors are displayed as an ellipse of uncertainty with the computer's best estimate of position at the center. The ellipse grows in area as the errors accumulate. As the autonomous vehicle moves, it is assumed to encounter known features or beacons, which it can detect. A Kalman filter integrates these observations with the computer's position estimates to provide an improved estimate of position, thus reducing the size of the uncertainty.

Other hardware and software used by ARRL include several CAD packages and a virtual Reality Toolkit developed by Dimension International (U.K.) for use with a 486-PC and SPEA Graphics Card. ARRL has integrated Dimension files with the SuperVision system, so that stereo imagery can be input to display devices such as the VPL headset.

Future Research Directions at ARRL

Telepresence is a long-term development process; diverse fields must be integrated. U.S. laboratories would look to expend perhaps $250,000 to enter the telepresence research area (typical is a high-end Silicon Graphics Workstation with expensive interface peripherals). ARRL is making do with less. With the current economic climate in the U.K., it is difficult to obtain the long-term funding necessary for an ongoing telepresence effort. ARRL has successfully sought work in virtual reality areas outside the telepresence testbed concept and now has a diverse, industry-supported development program.

W INDUSTRIES

W Industries is well known as a producer of virtual-reality games.[3] Dr. Jon Waldern, Managing Director and CEO, frequently speaks at U.S. conferences. Terry Rowley, another of the four cofounders, gave a STAR (State-Of-the-ARt) Report on virtual reality at the Eurographics '92 Conference. The company has been growing rapidly since its formation in 1988, currently employing 60 persons. Their projected turnover for 1992 is £11 million ($17.5 million).

An Adventure Game

I positioned myself standing in the "pod", placed the headset with the goggles over my head, tightened the pack around my waist, and held the joystick in my right hand. After some introductory graphics, I found myself in a 3-D room. As I turned in the pod, the magnetic sensors above me perceived my movements and the scene changed. Two doors lay ahead, one wooden and the other metallic (presumably iron). I faced the wooden door, pressed my joystick, and moved forward. I reached out with my hand and opened the door. I moved forward with the joystick, walking down a set of stairs. The new room contained a chest. After turning and "walking" over to it, I opened the chest and reached inside by holding out my hand. The 3-D display now contained my hand holding a sword. I heard a noise behind me. Turning in the pod, I faced two skeletons. Holding the joystick, I swung my arm as if I were holding a sword. Polhemus sensors interpreted my motion, and the skeletons dissipated at my blows. After investigating several more rooms and encountering other virtual beings and objects, I was killed in a swordfight. I had reached the sixth room on the first level.

The game, still in the development stage, was LegendQuest™ by W Industries. It showed the weaknesses, but also the promise, of virtual reality. The resolution of the LCD's in the head-mounted display are currently 200 by 300 pixels. At this low resolution, reading the large logo shown at the start of the program was difficult and scenes lacked sharpness. Besides hardware resolution, rendering more polygons and adding texture would help realism. The 200-ms delay was too slow to give a real sense of the virtual "me" reacting properly to my movements. W Industries hopes to see the delay reduced to 100 ms. The company also expects to add doppler effects to the sound processing. Magnetic sensors cannot be user-calibrated when the user changes every few minutes. As a result, the movement sensing was inexact quite apart from delay constraints. Force feedback data gloves would certainly aid the perception of realism as well. W Industries says they are working on all these improvements.

Still, I have watched my 11- and 15-year-olds play enough computer and Nintendo adventure games to observe the difference when virtual reality technology is used. The feeling of being a "character" is quite different from moving a "character" that is not you on a TV screen. And the emergence of virtual reality entertainment may well assist the growth of more serious virtual reality efforts, much as computer graphics from the entertainment industry provided a technology base for scientific visualization efforts in the late 1980s.

The game is interesting from an HCI viewpoint. The multi-player version is perhaps the first virtual reality game where the players work together with each other against a hostile environment. And the game is building-in the capability to integrate both real and imaginary features of a player. For example, voice synthesis will allow changing a person's tone to that of a character type while still maintaining certain characteristics of the real owner.

Low-End Virtual Reality

There are unique aspects in designing virtual reality hardware for arcade entertainment. The frame and peripherals must be indestructible, with the peripherals as isolated from the user as possible. The head-mounted display must fit both children and adults with a minimum of adjustment and distortion. W Industries develops their consoles and visors from glass-reinforced plastic. The computers are also housed safely away in the underbody. The joysticks, according to Rowley, are a military design that has been further ruggedized. A monitor on the front of the unit helps keep the interest of those waiting a turn. The system is specifically designed to allow passage through doors with minimal disassembly.

The computer is a combination of commercial and in-house development. A Commodore Amiga 3000 is currently used as the computing engine, although W Industries expects to switch to IBM PC technology to reduce cost even further. An in-house-developed graphics board made with Texas Instruments graphics chips provides higher graphics rates than available from the Amiga. Game software is stored on CD-ROM. In-house-developed software is used for graphics generation. Objects for games have been created by digitizing models, but W Industries is now moving toward generic modeling.

The helmet also is designed in-house, produced externally, and assembled (as are all components) in-house. The LCD for each eye is placed on the side of the helmet and viewed through a mirror. According to W Industries, this design keeps the weight back on the helmet for balance. The graphics software, of course, produces frames as mirror image. Two speakers are in each earphone. Polhemus magnetic trackers are used for both hand and head tracking.

The economics of a virtual reality arcade game dictates that the game must recapitalize itself in 6 to 12 months (some have done much better). The life expectancy of a game is 2 to 3 years. Games have been successfully released at several large arcades, including one in London. However, the difficulty with arcade games lies in the learning curve for players. Players must be willing to keep contributing tokens (at several dollars per minute)—an unrewarding undertaking until a certain skill level is obtained. W Industries is looking to the theme park and advertisement industries for growth while awaiting the day that home virtual reality games become possible over "telephone" links. An agreement with Paramount will see the construction of Star Trek Virtual Reality Centres where the player, as Captain Picard, will battle the Romulan Empire. A partnership between Sega and W Industries is establishing virtual reality as part of Sega's arcade development program.

DIVISION LTD.

Founded in 1989 by four persons who were key engineers in the U.K. parallel processing industry, Division Ltd. of Bristol, U.K., has become a leader in software and integrated solutions for virtual reality applications. The chairman of the company, Dr. Iann Barron, was a founder of INMOS Ltd. (producers of the Transputer parallel processing chip), and several members of the senior management also come from INMOS. Division believes that their May 1993 placing on the London stock exchange is a first for a virtual reality company world-wide. The offering raised £5 million ($7.5 million). The infusion of funds is being used for both new R&D and to expand their sales and marketing staff world-wide.

Division currently employs 30 people at their Bristol office. An additional 7-person support office is located in Redwood City, California, for sales and marketing in the U.S. Distribution in Japan is being handled by Matsushita Electric Industrial in Tokyo. Division expects to add an office in the Chapel Hill or Research Triangle area of North Carolina and to expand to 40-50 persons by the end of 1993. They have recently sold their first U.S. system to Aberdeen Proving Grounds (Maryland).

Hardware Products

Division offers both board products for personal computers (PCs) and integrated system products. At the board level, add-on accelerator boards are offered to support virtual reality on PCs. These boards include a stereo image generator and a real-time collision-detection board. We did not examine this product during our visit.

Division also offers several levels of workstations (called ProVision and SuperVision)[4] that are based on Intel 486 microprocessor architecture running UNIX. These provide stereo image generation with optional texturing, binaural audio synthesis, and user tracking. At the high end, video images from video cameras and computer-generated images can be combined. Division states that ProVision can render up to 35K Phong or Gouraud shaded polygons per second per eye (sustained performance), while SuperVision can achieve rates of up to 280K polygons.

The primary thrust of Division, however, is in software development. They are integrating their software packages to run on high-end UNIX workstations (currently SGI and IBM RS/6000, with SUN expected shortly). Given the number of potential virtual reality users who already own workstations, this approach makes sense.

The dVS Software Toolkit for Virtual Reality

dVS is an operating environment that runs on top of certain standard operating systems. The approach of dVS is to create specialized modules for different functions (which they denote as "Actors"). For logical reasons only, they divide virtual reality into three categories:

- sensing of the real environment,
- control of the virtual environment, and
- display of the virtual environment.

Each category then has Actor modules. For example, Real Environment Sensing might include Actors for gesture recognition, 3-D tracking, and speech recognition; Virtual Environment Control might include Actors for object behavior and collision detection; and Display might contain Actors for visual, audio, and haptics.

To allow for multi-user systems with multiple servers, a shared data space is created into which Actors may place shared objects called "Elements." Different Actors then model these Elements and respond to global changes. The fundamental object in dVS is an "Environment" (or shared data space) that can be accessed by a number of Actors. The Environment contains the Elements.

This structure offers users the advantage of being able to put together a virtual reality environment quite quickly—a higher level environment authoring language that sits on top of dVS is also offered by Division. Parallelization comes primarily from having the Actors operate in parallel. Thus, the software offers advantages on "lightly" parallel systems (e.g., an 8-processor SGI). Peripherals currently supported include, among others, a subset of those offered by Polhemus, Ascention, Logitec, VPL, Fake Space Labs, Virtual Technologies, Spatial Systems, Crystal River Engineering, and Division.

Division hopes to release improved versions of the dVS software and ports to other workstations about every 6 months. Anticipated near-term software improvements are in networking, collision detection, and the generation of high-level authoring tools for 3-D authoring of worlds while immersed.

Sample Applications

I was accompanied on this visit by Ms. Elizabeth Wald of ONR and several others from a U.S. delegation to Great Britain that she was chairing. The first application discussed below was of particular interest as some delegation members are contemplating a similar application.

The following are sample applications developed by Division or by others using Division software. Several of these were demonstrated to us. The standard limitations in virtual reality technology (low resolution, high response time from sensors, etc.) were noted in these demonstrations. However, several applications are at a functional, rather than research, stage. Division does not deal with most of these largely sensor-related problems; they will simply incorporate improved sensor technology in their software suite.

Architecture

Virtual reality is being used to design the operations room of the frigate HMS *Marlborough* for the Defence Research Agency - Maritime Division, Portsdown, U.K. A computer-based model using scaled measurements of the operations room was constructed by using AutoCAD. Realistic lighting was included by passing the AutoCAD models through a radiosity program.

Environmental Simulation

Based on Division's PROVISION system, the Living Environmental Systems Laboratory at Matsushita Electronic Industrial Co. has developed a system for simulating living environments in virtual reality. The goal is to provide building designers with an accurate simulation of the air conditioning, lighting, and acoustical characteristics of a room or building under design. The Thorn EMI Central Research Laboratories (U.K.) and the London Parallel Applications Center have studied lighting models to develop software for Thorn Lighting that will serve as an interface to the design process.

Manufacturing Design

A project has begun with the Computer-Aided Industrial and Information Design researcher group at the Coventry School of Art and Design. The goal is to replace the building of full-scale models with a virtual representation. This is the start of an anticipated long-term project to evaluate how virtual reality can be used to help a user interact with objects in their natural environment and thus perform design evaluation to identify features and flaws that might otherwise be overlooked until much later in the design process.

Molecular Modeling

Work at the Glaxo Group Research of the University of York is developing virtual reality tools for molecular modeling. The goal of the project is to allow a scientist to hold and manipulate a molecular shape while receiving real-time feedback about steric hinderance and other molecular interactions.

Training and Simulation

TNO-FEL (the Netherlands) has used Division software to develop virtual reality simulations of stinger missile firings and of spacewalks for training astronauts.

ASSESSMENTS AND CONCLUSIONS

In the late 1980s, the U.K. served as the springboard for European activities in virtual reality. It is not clear why this is so, although discussions with U.K. experts indicate that much activity arose from initial efforts at British Aerospace. Other factors include the support within the robotics program from DTI and the presence of INMOS, whose transputer chip has been heavily used in Europe for parallel computing. The three efforts discussed in this article cover very different areas within the virtual reality arena, and all are well-recognized efforts within the European community. W Industries and Division are both commercially successful and growing, although they face pitfalls of competition and direction that must be met by any small high-tech company in a growth area. Both are well-placed within their segment of the industry. It remains to be seen if each can chart a growth path that correctly predicts what turns this new technology will take.

The case of ARRL is perhaps more interesting. ARRL once stood for Advanced Robotics Research Laboratory (instead of Ltd.) and had significant governmental funding. The U.K. has, over the last several years, suffered from a severe recession (worse than other major Western European countries). U.K. university research teams, including ARRL, were forced to become increasingly commercial to obtain any funding. Telepresence is a virtual reality topic that requires much ongoing research, and it is difficult to see how ARRL's telepresence effort can be maintained without government funding. As a result, the U.K. is likely to lose its lead within Europe in this area. Although new to the virtual reality community, major German R&D organizations such as the German Center for Mathematics and Computer Science (GMD) and the Fraunhofer Institute for Computer Graphics (FhG-IGD) have recently devoted both significant funding and research personnel to virtual reality. It is here, rather than in the U.K., that European strength is likely to develop over the next several years.

Europe has been slow to formally recognize the importance of virtual reality. There is no current ESPRIT[5] program in virtual reality, although the next round of funding in 1995 is expected to contain a virtual reality component. This should be contrasted with Multimedia, which is one of the seven major thrust areas in the Information Technology portion of ESPRIT. Virtual reality is mentioned within other thrust areas, but only briefly as a tool. The U.S. has been more active in nuturing this field, with ONR, the National Science Foundation, and the Advanced Research Projects Agency funding research and development efforts.

Virtual reality is a very dynamic research topic, with many new efforts springing up. As noted above for Germany, given funding and personnel a top-flight organization can become a "player" in a relative short (say, 2-year) period. To further assess trends and directions in European virtual reality, the ONR European Office has cooperated with Eurographics to initiate a workshop. The result is the 1st Eurographics Workshop on Virtual Environments, to be held in September

1993, the day before the start of the Eurographics'93 Conference in Barcelona, Spain. This workshop will be the topic of a separate report.

REFERENCES

1. H. Rheingold, "Teledildonics and Beyond," Chapter 16, in *Virtual Reality* (Simon and Schuster, New York, 1991).
2. R. Stone, "Virtual Reality and Telepresence," *Robotica* **10**, 461-467 (1992).
3. T. Rowley, "Virtual Reality Products," in *Virtual Reality Systems*, R.A. Earnshaw, M.A. Gigante, and H. Jones, eds. (Academic Press Ltd., 1992), pp. 39-50.
4. C. Grimsdale, "Supervision—A Parallel Architecture for Virtual Reality," in *Virtual Reality Systems*, R.A. Earnshaw, M.A. Gigante, and H. Jones, eds. (Academic Press Ltd., 1992), pp. 29-38.
5. R. D. Ryan, "ESPRIT—A Guide to Structure and Literature," *ESNIB* **90-06**, 41-46 (1990).

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Electronics

III/V-Electronics in Germany: Focus on the Fraunhofer Institute for Applied Solid State Physics in Freiburg

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KEYWORDS: research programs; lasers; MMIC; semiconductors; measurements

INTRODUCTION

The Fraunhofer-Gesellschaft (FhG), founded in Munich in 1949, is one of the key German institutions dedicated to the advancement of applied research. Unlike the Max-Planck-Gesellschaft, which is the premier organization dedicated to basic research in the Federal Republic of Germany (FRG), the FhG's charter is to bridge the gap between the research community and market-driven establishments. Its 45 separate institutes represent 9 different disciplines within the natural and physical sciences and serve as links in this technology transfer process. The FhG philosophy is based on the concept of taking research-spawned ideas, developing them into prototype entities, and then transferring them to the commercial sector. The institutes are the facilitators in this transfer process.

This report outlines the III/V electronics research strategy in the FRG. It focuses on activities in monolithic microwave and millimeter wave integrated circuit (MMIC) and optoelectronic integrated circuit (IC) development at the Applied Solid State Physics Institute of the Fraunhofer Society (FhG-IAF) in Freiburg. This report is based on recent site visits and discussions with staff. Design, processing, and measurement methodology is described, and highlights from recent technological breakthroughs in MMICs and optoelectronic ICs are presented. Appendix A lists names and addresses of the institutes that are doing applied research in microelectronics.

The total budget for the Fraunhofer institutes in 1992 was more than DM 1 billion (about U.S. $650 million). Most of the money comes from the Federal Ministries and the private sector in the form of contract research grants. About 90% of this total is used to fund research and development (R&D) activities; the remaining 10% is reserved for construction of new facilities and purchasing new equipment. The Fraunhofer institutes employ about 6,500 people.

One of the strong points of the FhG concept is the built-in flexibility of the institutes to provide opportunities for scientific interaction among various research and industrial establishments. It is not uncommon to find professors directing research projects at universities, developing the prototype concepts at some FhG institute, and then fabricating and selling these developed products on the open market. The system fosters entrepreneurship and contributes to the competitiveness of German industry in the global market environment.

Eight of the FhG institutes are dedicated to applied research in microelectronics. These are designated as Fraunhofer Institutes for:

- Applied Solid State Physics (IAF), in Freiburg
- Solid State Technology (IFT), in Munich
- Integrated Circuits (IIS), in Erlangen
- Integrated Circuit-Device Technology (AIS), in Erlangen
- Microelectronic Circuits and Systems (IMS), in Duisburg
- Microelectronic Circuits and Systems (IMS-2), in Dresden
- Microstructure Technology (IMT), in Berlin
- Silicon Technology (ISiT) in Berlin.

The FhG-IMS-2 in Dresden is a newly formed Fraunhofer "Establishment" that will soon become a full-fledged member of the FhG. The FhG-ISiT in Berlin is in the planning stage and is under the supervision of IMT-Berlin.

THE FhG INSTITUTE FOR APPLIED SOLID STATE PHYSICS

The Fraunhofer Institute for Applied Solid State Physics (Fraunhofer-Gesellschaft Institut für Angewandte Festkörperphysik, FhG-IAF) in Freiburg, is the FhG institute dedicated exclusively to the advancement of the science and technology of GaAs-based electronics. Established in 1957, its main R&D charter is the technical advancement of III/V electronics and optoelectronics. The IAF is also involved, to a lesser extent, in infrared solid state physics and display technology. (Appendix B is a detailed listing of IAF research topics and group leaders.)

Organization, Management, and Funding

For the past eight years, the IAF has been headed by Prof. Hans Rupprecht, a world-renowned figure in semiconductor technology. Professor Rupprecht, formerly R&D director at IBM, has attracted talented young scientists and engineers to IAF. He has established a world-class GaAs facility that is spearheading a major thrust in monolithic microwave and millimeter wave integrated circuits (MMIC) and optoelectronics in FRG and Europe.

Although management of IAF is under Prof. Rupprecht's direction, research policies for the institute are set by a Board of Directors, which is composed of representatives from the government, industry, and academia. Board members include:

- the president of the FhG and the director of the IAF;
- government executives from the Ministry of Defense and the Ministry for Research and Technology;
- industrial advisors from Telefunken, Standard Elektronik Lorenz, Siemens, and Wacker; and
- renowned university scientists (such as Prof. Lester Eastman from Cornell University,

Prof. Manfred Pilkuhn from the University of Stuttgart, and Prof. Hans-Joachim Queisser from the Max-Planck Institute in Stuttgart).

The operating budget of IAF in 1993 was DM 30 million (U.S. $20 million). Most of the funding comes from the German Ministry of Defense and the Ministry for Science and Technology. Additional funds come from industrial partners such as Siemens, Telefunken, SEL-Alcatel, and Daimler-Benz.

IAF Facilities

The IAF laboratory is located at the Tullastrasse 72 in Freiburg. A new clean-room building was constructed here in 1991. This 2,000-m^2, Class 100 clean room processing facility can truly be termed a GaAs "fab-line" for German industry and academia. The clean-room facility houses three Varian GEN-II MBE epitaxial growth units and is capable of processing about 1,000 GaAs wafers per year. Both the epitaxial growth and processing facilities are available for internal and external R&D projects.

Along with the adjacent laboratory facilities, IAF has the capability to design and test new ICs, both for MMICs and optoelectronics, with state-of-the-art equipment. All aspects of design, processing, testing, and associated statistical data are stored and monitored by a central computer.

The laboratory (which includes display and other R&D activities) employs about 210 people. Of these, 81 are researchers, 91 are technicians, and 16 are administrators. The remaining staff comprise visiting scientists and doctorate and Diplom. candidates.

NATIONAL FOCUSED PROGRAMS IN III/V-ELECTRONICS

Consortium in III/V-Electronics

One of the two major research initiatives in which the IAF is a partner and coordinator is the German "III/V-Elektronik" project. Started in 1991, this 4-year national focused research program established three working groups. Its primary responsibility is initiating investigations in the following three areas:

Working Group A:
High-speed/frequency-integrated circuits
Working Group B:
Mesoscopic structures
Working Group C:
Integrated functions.

Each working group comprises "partners" from Fraunhofer, Max-Planck, industry, and university laboratories (these are listed in Appendix C).

Group A concentrates on projects that have potential for transition to the civilian sector. The goal is to develop the technology of high-frequency integrated circuits for future electronic systems—systems that will have an impact on transportation safety, monitoring of the environment, and communications. The Germans anticipate an increased demand for

- safer transportation-related systems, such as collision-sensing radars;
- new environment monitoring systems, such as millimeter-wave sensors and systems for traffic control; and
- new communication systems, such as short-distance communication using millimeter waves and ultra-high data rate transmission in fiber-optic networks.

All of these applications call for higher complexity and degree of integration in the microelectronic chip.

Partners in Group B concentrate on III/V semiconductor structures of very small dimension. Structures in this nanometer-scale or quantum regime reveal interesting new electronic and optical properties and have led to new electronic device concepts. Examples of some of these new structures include quantum wells, -wires, and -dots. Applications include very efficient quantum-well lasers, very fast transistors, and new detectors for the near and far infrared.

Group C is responsible for integrating these mesoscopic structures into functional elements and leaping into the domain of "nanoelectronics," a realm way beyond the limits of present-day electronics. The kernel of this research is the development of new tools that will allow the realization of multi-functional circuit elements, e.g., electronics and optoelectronics on the same chip.

It is hoped that the III/V-Elektronik research consortium will enable the German semiconductor industry to achieve a competitive edge in the micro-and opto-electronic IC technologies. This goal also would secure a larger demand for German-made GaAs substrates, which until recently had dominated the world GaAs market.

Consortium in Photonics

The second research initiative in which the IAF is playing a major role is the German "Photonik" project. Started in 1990, the objective of this 4-year focused program is to develop integrated optoelectronic components (e.g., laser sources, detectors, and optical couplers) and use them in prototype communication systems. The realization of such systems hinges on two compound semiconductors: InP for the 1.3-1.5 μm, and GaAs for the shorter 1-μm wavelength applications. The leading coordinators for this two-tier project are: for InP, the FhG Heinrich-Hertz-Institut for Telecommunication in Berlin; for GaAs, it is the FhG-IAF in Freiburg. A total of 15 institutions are involved in these projects

There is no question that the IAF is playing a leading role in both the III/V-Electronics and Photonics projects. This is clearly shown by the prolific R&D output of the IAF staff. Details of these development are described below.

GERMAN MMIC DESIGN AND PROCESSING STRATEGY

Instead of emulating MMIC development trends in the U.S. and Japan, FhG-IAF decided from the beginning to develop their own design and processing strategy in producing high-frequency MMICs. Unlike the Department of Defense (DoD) MIMIC project in the U.S., which (at the moment) is mostly ion-implantation-based, the FhG-IAF jumped directly into advanced epitaxial-based MMICs—using the latest breakthroughs in high electron mobility transistor (HEMT) and pseudomorphic-HEMT (PM-HEMT) technology. By using molecular beam epitaxy (MBE) growth and advanced computer-aided design (CAD), the FhG-IAF established their own design, simulation, and processing criteria. Processing, for example, relies heavily on mixed photo- and electron-beam-lithography, T-gate (the so-called mushroom FET gate), and low-voltage reactive ion etching. Driven by lack of experience with microstrip line fabrication techniques, the German team decided from the start to develop coplanar transmission line design concepts for efficient transmission of signal within the IC chip.

This radical new approach has placed the German III-V electronic industry in a strong position in producing high-frequency MMIC in the V and W band. The German MMIC design strategy is beginning to pay off.

Coplanar Waveguide Technology

A key element in microwave/millimeter wave monolithic IC development is the efficient transmission of the signal within the IC chip. This can be achieved by one of two ways:

- transmitting the microwave signal between a metal strip (microstrip) and a ground plane on the other side of the GaAs wafer, or
- placing both the transmitting strip and the ground plane on the same side of the wafer (coplanar).

Each of these techniques has advantages and disadvantages. The microstrip line approach requires backside via hole processing and thinning; the coplanar transmission line (or coplanar waveguide, CPW) approach is simpler, more economical, and offers better shielding and lower velocity variation with frequency or impedance. Most of the design rules that use microstrip lines are well known by the MMIC community. CPW, on the other hand, is in its infancy when it comes to design and modeling database. Additional disadvantages for coplanar lines include higher attenuation and lower effective dielectric constant, which lead to slightly larger dimensions in the circuit design. Nevertheless, the fact that coplanar technology is a totally planar technology, fully compatible with HEMT technology, outweighs the disadvantages This is making it increasingly popular in monolithic integration.

The FhG-IAF, in collaboration with the High Frequency Physics Institute in Darmstadt, has developed a simplified CPW model that aids the design of millimeter circuits. Signal attenuation as a function of frequency for various geometrical parameters (such as metal thickness, line size, and ground-to-ground spacing) have been calculated for GaAs, InP, and quartz. Analytical results agree remarkably well with experimental data extracted from on-wafer S-parameter measurements up to 60 GHz.

The analytical results led to the following design criteria:

- The impedance and attenuation for GaAs and InP are almost identical (because they have similar dielectric constant). The attenuation in quartz is almost a factor of four lower than in GaAs and InP.
- The maximum ground-to-ground spacing that still allows quasi-TEM wave propagation to take place is $l/10$, where l is the wavelength along the line. This means that, for an operating frequency of 60(90)[140] GHz, ground-to-ground spacing less than 140(90)[60] μm for GaAs or InP and 240(170)[120] μm for quartz, is required.

As a result of these analyses, design rules have been established for optimizing MMIC performance. For example, in addition to using optimum CPW layout on the chip to achieve peak MMIC performance, the German engineers use CPW lines on quartz to minimize losses when coupling on-chip MMICs with external waveguides.

Processing Standards and Yield

The FhG-IAF strategy for success in GaAs ICs is similar to that of the Japanese: develop the prototypes, get a sufficient number of wafers through processing to establish yield statistics, and make improvements; then transfer know-how to industry by duplicating the process methodology and training new employees.

FhG-IAF is offering a standard process to the customer. This entails a double-delta-doped PM-HEMT with gate lengths of 0.3 μm; fabrication of enhancement (E-HEMT) and depletion (D-HEMT) transistors; metal-insulator-metal (MIM) capacitors; and airbridge inductors. The interconnection between different devices is achieved by two levels of metallization. The process enables the fabrication low-power high-speed analog and digital circuits on the same chip.* Design tools for customers include: design manual, standard layout for circuit elements, IAFSPICE circuit simulator, design consulting, and verification.

A measure of success for this process can be found in wafer yield figures. Based on a 2-year study, the MBE wafer yield at FhG-IAF is 47% (test, plus processed wafers). Of these, they get a 87% processing yield on 0.3-μm gate circuits. The yield drops with the number of gates per wafer to 80%, 60%, and 10% for 100, 1,000, and 10,000 gates/wafer respectively. For the 0.3-μm gate size, limitation is due to metallization.

For advanced 0.1-μm gate circuits, the yield is 50% for 100 gates/wafer. The active device is the limiting factor. The small gate geometry imposes stringent control on the MBE growth (doping and thickness). To achieve good reproducibility, temperature control on the source ovens better than $\pm 2\%$ is required. Such control must be maintained over a long period of time to ensure high quality ICs. FhG's strategy to improve yield is to:

- *use the same people to do the processing,*
- make the individual technician responsible for all the process steps,
- use the same MBE machine for a given project,
- avoid using part-time helpers such as students, and
- require "cradle-to-grave" documentation.

Typical processing time at IAF of a designed chip is 3 weeks.

High-frequency Measurements

Testing of the processed chip is the third key element of the design-processing-measuring cycle. To this end, the FhG-IAF scientists and engineers

Typical performance for E-HEMT: V_t=0.05 V, g_m=470 mS/mm (V_{gs}=0.6 V), I_{ds}=175 mA/mm (V_{gs}=0.6 V), R_s=0.7 ohm-mm, f_t=50 GHz; for D-HEMT: V_t=−0.7 V, g_m=350 mS/mm (V_{gs}=0 V), I_{ds}=180 mA/mm (V_{gs}=0 V), R_s=0.6 ohm-mm, f_t=42 GHz.

have developed a single 4-probe station capable of measuring on-wafer S-parameters from 45 MHz to 80 GHz continuously. It uses the latest U.S.-designed Cascade probe and x-y stage, which allows wafer mapping of the S-parameter. The measuring unit combines the 45 MHz-50 GHz coaxial signals with the 50-80 GHz waveguide at a diplexer; the combined signal is then transmitted over a short coaxial line to the probes. System losses are severe (10-15 dB), but the scheme works. From the S-parameters, in-house-developed software is capable of calculating all the important device parameters. From these, the MMIC performance can then be compared with circuit model simulation.

The IAF engineers have a close working relationship with the Hewlett-Packard microwave instrumentation division and consequently have access to the latest innovations in millimeter-wave measurement development.

RECENT MMIC ACHIEVEMENTS

The 0.18-μm Gate PM-HEMT for MMICs

Some of the major successes credited to IAF include the design and processing of a MMIC amplifier based on a 0.18-μm gate (pseudomorphic) PM-HEMT (25% In in the InGaAs channel). The 2-stage version has a gain of 10 dB at 60 GHz with a noise figure of 4 dB. A 3-stage unit has a 37 dB gain. In partnership with Daimler-Benz, the IAF is also developing an active phase array IC consisting of a 4-bit analog phase shifter integrated with a digital controller.

W-band Amplifiers Using CPW Technology

Another notable success is the development of a 5-stage distributed amplifier with a gain of 9.3 dB over the frequency range 5-60 GHz (with a noise figure less than 4.3 dB up to 60 GHz); and a narrowband 3-stage low noise amplifier (LNA) with more than 21 dB gain between 70-80 GHz (with a noise figure of 6.4 dB at 76 GHz).

Both of these millimeter-wave MMICs are fabricated by using 0.16-μm T-gate pseudomorphic AlGaAs/InGaAs/GaAs HEMT technology. NiCr thin-film resistors, MIM-capacitors, and SiN passivation are used in the transistor fabrication. Two metallization levels, including airbridges, allow the connections between the active devices, the matching networks, and the MIM capacitors. CPW technology is used throughout.

To avoid amplifier instability, each stage of the distributed amplifier uses a cascaded pair of transistors. The input transistor is operated in common source configuration and the output transistor in common gate configuration. The gate of the second transistor is capacitively grounded and can be used for gain control. In this configuration, the effective feedback capacitance is minimized and Miller feedback is reduced. The overall dimension of this distributed amplifier is 0.6×1.5 mm square.

The FhG-IAF group claims that these MMIC amplifiers are the first to use coplanar waveguide technology; the 21 dB gain from 70-80 GHz is believed to be the highest gain yet reported on any MMIC amplifier above 40 GHz for both GaAs- and InP-based circuits.

Comparison to U.S. MMIC Development

This MMIC performance should be compared to the latest (August 1993) MMIC developments in the U.S. Both Martin Marietta and TRW have fabricated MMICs that show comparable W-band performance.

With funding from the Navy, Martin Marietta has fabricated a 3-stage, 0.1-μm gate, InP-based HEMT LNA showing a 10.5 dB gain between 75-110 GHz (with a noise figure of 3.5-5 dB over this frequency range). A similarly designed 4-stage, GaAs-based MMIC had a 21 dB gain over the full W-band. Both of these MMICs use conventional microstrip technology.

Recently, H. Wang from TRW has reported a 3-stage, GaAs-based, PM-HEMT MMIC amplifier exhibiting a noise figure less than 4 dB with an associated gain of greater than 21 dB from 91-97 GHz.

This comparison shows that the German MMIC technology is on par with state-of-the-art MMIC developments in the U.S. and should be closely monitored.

ACHIEVEMENTS IN OPTOELECTRONICS

High-speed 10-20 Gbit/s GaAs/AlGaAs Data Links

Optical fiber links with extremely high data rates are required for long-haul telecommunication networks, as well as for numerous short-haul applications such as in supercomputers, local area networks, and high-frequency instrumentation. The long-haul telecommunication industry has concentrated on the 1.35-1.55 μm low-loss transmission window in the fiber media and has targeted InP material as the basic building block for system development. Although the FRG is pursuing R&D in InP-based optoelectronics at various national and industrial laboratories, the FhG-IAF in Freiburg pursues research primarily in GaAs-based (0.85-μm) optoelectronics. By using their advanced GaAs IC processing facility, they have developed one of the fastest optical data links to date.

The optical data link system consists of three parts: the transmitter, the fiber link, and the receiver. The transmitter contains a clock, a 4:1 multiplexer that serializes the parallel data stream, and a laser driver that amplifies the serial data stream and delivers the DC current to the AlGaAs/GaAs laser diode. The receiver entails a metal-semiconductor-metal (MSM) photodetector integrated with a transimpedance amplifier, a bit synchronizer, a clock, and a demultiplexer. The transmitter and receiver are processed as separate chips. The laser is separate from the driver, but efforts are being made to integrate it within the same transmitter circuit.

All chips are fabricated by using the same recessed-gate process for double delta-doped quantum well HEMTs. Both enhancement and depletion types of transistors are realized on the same MBE-grown wafer by using AlGaAs etch stop layers and selective reactive ion etch process. Electron beam lithography is used to define the 0.3-μm transistor gate lengths and the fingers of the MSM photodiode. The fabrication process also includes NiCr resistors, MIM capacitors, and two metal layers for device interconnection.

To reduce power consumption, E/D direct-coupled FET logic is used in logic circuits, and source-coupled FET logic is used for those functions having the highest speed requirements. Individual circuit elements show the following performance:

Multiplexer: maximum data rate for a single 2:1 multiplexer is 20 Gbit/s

Laser driver: output data rate is 18 Gbit/s when integrated with a 2:1 multiplexer

Transimpedance amplifier: small signal bandwidth exceeds 14 GHz; sensitivity of the circuit is -15.3 dBm, as calculated from noise spectrum

Demultiplexer: the 1:4 demultiplexer was tested to be functional at 11 Gbit/s.

The systems have been successfully operated with data rates in excess of 10 and up to 20 Gbit/s. Such success indicates the seriousness of FhG-IAF in developing the monolithic integrated transmitter and receiver for optical communication links in the foreseeable future.

New, Efficient, High-speed, 20 GHz Bandwidth Lasers

Scientists at the FhG-IAF have also designed, fabricated, and tested $In_{0.35}Ga_{0.65}As/GaAs$ multiple quantum well lasers with undoped and p-type modulation-doped active regions operating in the 1080-1090 nm wavelength band. Modulation bandwidths, f (3 dB), of 20 GHz were typically obtained at CW drive currents of 50 mA for the modulation doped, and 60 mA for the undoped laser, respectively. These values are lower than those previously required to achieve equivalent modulation bandwidth. For a CW bias current of 114 mA, the direct modulation bandwidth was 30 GHz. *This is the highest direct modulation bandwidth ever reported for any semiconductor laser*.

As mentioned before, one of the major technical hurdles has been the integration of the laser driver with the laser. IAF is close to overcoming this hurdle. Recent reports from IAF indicate success in integrating the laser diode with the driving circuit. The fabricated 360-μm long and 4-μm wide quantum-well diode laser has a room-temperature threshold current of 28 mA, a series resistance of 22 ohms, and a quantum efficiency of

45%. The measured optical data rate of this IC is 7.4 Gbit/s (which was limited by the speed of the receiver). The laser cavity for this IC was produced by cleaving; such cleaving imposes space limitations for the driver circuits. Efforts are being made to use dry etched laser mirrors to remove such space limitation. This will allow the addition of a 8:1 muliplexer to the IC and will lead to a fully integrated optical transmitter.

ASSESSMENT AND CONCLUSIONS

It is indisputable that FhG-IAF is a first-class III/V R&D facility. It has shown itself to be innovative and a pace-setter in the world of high- technology electronics. It has some of the latest state-of-the-art design, processing, and testing facilities available, and a highly trained and talented group to operate it. The management is efficient and the R&D is well focused. The long-term R&D strategy in all aspects of MMIC and optoelectronic IC development is excellent and bodes well for the future of FhG-IAF.

In spite of these successes, it is worth airing some of the concerns that managers of laboratories such as FhG-IAF face and will face in the future.

The first hurdle is the technology transfer process to industry and the eventual creation of marketable products based on these new technologies. This concern is not unique to the German or European R&D establishments. U.S. and Japanese high-technology firms are facing similar challenges. The recent downturn in the global economy places additional hurdles on this task.

In the case of MMICs, a new commercial market will have to be created to absorb the newly developed chips and the systems built from them. Such markets now exist mainly in the defense sector. In the U.S. in the past 5 years, DoD has invested heavily in developing MMICs, with the hope of improving the performance of present and future radar systems. DoD is banking on the promise that by investing in MMICs, it will drive down the procurement costs of such systems—provided that the technolgy will spill over into the commercial sector. Initiatives such as the MIMIC ARPA/Tri-Service program are heavily subsidized by government. It is imperative that now, when DoD is facing major cutbacks, programs such as MIMIC find continuity in the private sector.

Similar concerns can be heard in the FRG. According to Hans Rupprecht, director of IAF, MMIC technology is racing ahead of commercialization. German electronics industries are conservative in adapting new technologies, especially ones based on semiconductors other than silicon. Many of the German electronics industries are also facing a downturn in their profits. As an example, Wacker-Chemitronic, the pioneer in GaAs electronics and the world-leading manufacturer of GaAs wafers, has sold its GaAs production facilities to Freiberger Electronic Materials (Freiberger Elektronikwerkstoffe, FEW). The new GaAs production facility is located in Freiberg/Sachsen, in the former German Democratic Republic (GDR). Unfortunately, for the German (and world) III/V community, much of the equipment and little of the know-how was transferred to Freiberg. According to experts, the GaAs wafers from FEW are not "quite the same" in quality as those formerly made by Wacker. This strategic gaffe may cost FRG momentum when the time comes to produce large quantities of advanced electronic components based on GaAs.

The prognosis for the development and utilization of advanced GaAs-based MMICs is even less optimistic in other European countries. France's Thomson-CSF is cutting back its R&D in high-frequency MMICs, the U.K. is a few years behind, and Philips of The Netherlands is still not sure what strategy to follow.

The situation seems more optimistic for optoelectronics. The telecommunication industry is pushing hard to implement the latest innovations coming out of the research laboratories. The reason is competition. Although many of the key telecommunication companies in Europe are nationalized, there is a trend lately to allow new enterprises to compete in the communication market. The newcomers all come armed with the latest state-of-the-art electronic and optoelectronic components in order to be more competitive.

At first glance it seems unfortunate that the IAF is concentrating primarily on GaAs-based components, not on InP-based development as pursued by the rest of the telecommunication groups. On reflection, however, IAF may indeed be on the right track in advancing a more mature GaAs-based technology. As evidenced by the progress made both in MMICs and optoelectronics, IAF had a fast rise on the GaAs-based IC learning curve and is now in a much better position to transition its IC ideas to industry. This does not mean that it is giving up on InP-based technology. On the contrary, IAF wants to use the well-developed GaAs-based infrastructure to launch new InP-based initiatives. It is only a matter of time. The IAF has already started in this direction by installing a new organometallic vapor phase (OMVPE) reactor dedicated to InP-based epitaxial growth research.

As it stands, R&D MMIC and optoelectronic efforts at FhG-IAF will continue at the present high level. The Germans understand the key technical issues associated with these technologies and are pursuing a sound R&D strategy. It is imperative that the U.S. keep abreast of their efforts and forge closer links with some of their programs, especially in MMIC development.

Whatever the economic or political climate, the German engineers and scientists will continue finding resonance with their U.S. colleagues in the R&D arena of MMICs and optoelectronics. And we all may just end up saying: "GaAs is the material of today, not just of the future."

Appendix A

Fraunhofer Institutes Doing Applied Research in Microelectronics

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Institut für Siliziumtechnologie (ISiT)
(Institute for Silicon Technology)
(to be set up in Itzehoe) contact:
Prof. Anton Heuberger at IMT

Appendix B

Research Topics Pursued at IAF

III/V components and circuit development
- millimeter-wave circuits
- diode lasers
- D/A and A/D converters
- ASICs and semi-custom-made integrated circuits
- Group leader: D. Manfred Berroth, Phone: +49(761) 5159-556

III/V process technology
- plasma physics
- semiconductor characterization
- mask fabrication, repair, and testing
- dielectric and semiconductor film deposition
- surface passivation
- processing of ICs
- Group leader: Dipl. Phys. Theo Jakobus, Phone: +40(761)5159-325

Materials research in compound semiconductors
- electron spin resonance and Raman spectroscopy
- electronic transport measurements
- surface analysis (AES and SEM)
- Group leader: Dr. Jürgen Schneider, Phone: +49(761)5159-500

Infrared solid state and device physics
- detector technology
- optoelectronic structures
- diamond thin films for heat sink and optical coatings
- Group leader: Dr. Peter Koidl, Phone: +49(761)5159-350

Display technology
- liquid crystal display (LCD)
- LCD large-area display
- electrochromic technology
- Group leader: Dr. Günther Baur, Phone: +49(761)5159-448

Material and processing
- Hall measurements
- noise measurements
- microwave and millimeter-wave measurements
- IC test structure measurements
- Group leader: Dr. Wolfgang Jantz, Phone: +49(761)5159-510

Laser diodes and exploratory technology
- fabrication and testing
- dry etching, sputtering, and metal deposition
- field effect and bipolar transistors
- laser diodes
- Group leader: Dr. John Ralston, Phone: +49(761)5159-340

Appendix C

German Industrial and University Laboratories Participating in III/V-Electronics and Photonics Programs

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Materials

Ceramic Matrix Composites Technology in Europe: An Update

by Anthony G. Evans, former Liaison Scientist for Structural Materials at the Office of Naval Research European Office while on leave from the Materials Department of the University of California, Santa Barbara.

KEYWORDS: ceramic matrix composite, subelements, chemical vapor infiltration, ultimate tensile strength, oxidation

INTRODUCTION

Both France and the Federal Republic of Germany (FRG) are pursuing very strong programs in ceramic matrix composite (CMC) technology. Integrated manufacturing and design is the distinctive, central theme of each of these programs. The concept is to design, manufacture, and test small components and subelements in a rapid turnaround time to identify the critical engineering problems. Flexible manufacturing techniques capable of making components with complex geometry have thus been emphasized. In France, the main effort is on chemical vapor infiltration (CVI); this is led by the European Propulsion Company (SEP). In the FRG, a variant on SILCOMP is being used, led by the German Aerospace Research Establishment (DLR).

I have the impression that the combined practical experience on CMCs gained in France and the FRG is substantial. They understand the most critical design issues and have some novel solutions. The U.S. would benefit from an exchange of information in this area.

ACTIVITIES IN THE FEDERAL REPUBLIC OF GERMANY

There is a larger effort in ceramic matrix composites in the FRG than I had realized. However, it does not appear to be as coordinated as the French program. Some of the highlights that emerged are as follows:

Materials

There is a ceramic fiber effort in FRG, located at Hoechst. They are using a polymer precursor method and have done a thorough study of crystallization. From these activities, a Si_3N_4 fiber has been developed. It is polycrystalline, not amorphous, and appears to exhibit much better high-temperature properties than Nicalon fibers. In fact, it seems to be a Si_3N_4 equivalent of the new β-SiC Dow Corning fiber.

Some basic work on polymer precursors is underway at the Max Planck Institut (PML) in Stuttgart, under the leadership of Prof. F. Aldinger (he was formerly a research director at Hoechst). Related basic research is being used to develop the appropriate chemistry for external coatings that impart oxidation protection to CMCs. The basic composition is SiCN, but it includes B, Al, and Ti. The latter elements influence crystallization, viscosity, and other factors relevant to oxidation protection. This activity is in collaboration with DLR.

Design

Design, manufacturing, and testing experience on SiC/SiC and C/SiC composites is at a high level. The German effort appears to be quickly catching up with the French. Both DLR and MAN Technologie have produced components and subelements. They have conducted appreciable testing, subject to large temperature gradients, under internal pressure; these tests have emphasized axisymmetric shapes. They have also conducted attachment tests, mostly using superalloy bolts, but also on brazed joints. They always find that the material capability is *underpredicted* when linear thermoelastic finite-element codes are used. The group at MAN Technology has thus developed a nonlinear code to predict stress redistribution. The code is still crude, but they are working on an improved version.

They admit to some problems with inter-laminar shear, particularly on the CVI SiC/SiC material. At this stage, they use double notch specimens to collect shear properties and apply these data to predict performance by using linear computations. I could not find out how well this works.

A group at the DLR, headed by Prof. Richard Kochendorfer, has for many years been engaged in manufacture and design with composites, working in collaboration with German industry. Examples of their expertise include:

- design of a metal matrix composite fan blade that minimizes attachment problems; and
- low-cost, automated manufacturing of polymer matrix composite components for automobiles, based on thermoplastic materials that can be warm-forged to shape.

In the ceramic matrix composite area, they have implemented a low-cost manufacturing process that can be used to make components and subelements. A design, manufacture, and test methodology has been used to understand the critical problems in the application of CMCs. With this approach they have manufactured and tested small combustors, nozzles, ducts, and attachments. The material is C/SiC for use in short-life, high-temperature re-entry applications. For such purposes, the material has performed remarkably well, at temperatures up to 1600°C. They are developing a comparable material, based on ceramic fibers, which could be suitable for long-life applications.

The manufacturing approach is based on two concepts: low cost and acceptable oxidation resistance. They begin with woven T300 carbon fibers. They infiltrate with a polymer having a high carbon yield. They then pyrolyze and heat treat to create a well-defined periodic network of translaminar shrinkage crack, leaving minimal porosity *within* the intervening fiber bundles. They then infiltrate with molten silicon (son of SILCOMP). The last step creates an interconnected, dense, SiC honeycomb framework around the C/C bundles, with less than 5% residual Si. The Si liquid only penetrates into the C/C bundle for about two fiber diameters, provided that the pyrolysis/annealing step has been performed correctly. *This is the critical step in the manufacturing*. When done correctly, they have no problems in the siliconizing step. The manufacturing thus involves a simple three-step process: infiltration, pyrolysis, and siliconization. It is also compatible with manufacturing experience on polymer matrix composites. The material is essentially fully dense and has good thermal conductivity (10-15 in S.I. units). As expected, there are periodic microcracks in the SiC caused by the thermal expansion mismatch. Nevertheless, the material performs remarkably well at temperatures up to 1600°C in oxidizing atmospheres.

The material cannot be expected to have long-time durability at high temperatures because of the C fibers and the cracks in the SiC framework.

However, a variation on this method is being tried using coated ceramic fibers. This may be attractive as a low-cost method, capable of producing SiC/SiC composites with adequate durability and mechanical properties. Kochendorfer would be interested in discussing this possibility.

The components being tested are remarkably similar to those being developed in the U.S. They are concentrating on thin-walled components subject to large axial thermal gradients, (~400°C/cm), plus internal pressure. *They have not experienced any failures as a result of these gradients.* Their proble' is have been in attachments, on which they are no' concentrating. They have the special requirement that the attachment regions be hot, and they cannot use superalloy bolts. Mechanical attachment concepts based on an all-ceramic composite design are being explored.

Monolithic

Research on monolithic Si_3N_4 for valves continues. Cost is still the biggest factor. The preferred approach is to use gas pressure sintering to minimize manufacturing costs. However, they have problems with vapor phase transport during sintering that has yet to be solved. Most importantly, they have oxygen removal from the surface, which results in a low-strength outer layer. For test purposes, they machine away this layer. But that approach is too costly for the actual application. Solving the vapor phase phenomenon, by using different gas mixtures and by preconditioning the furnace hardware, is a major priority. The relatively high cost of the Si_3N_4 powder is also a problem. But this may be acceptable, if adequate thermomechanical performance can be achieved in as-sintered parts.

ACTIVITIES IN FRANCE

Since my visit to France in November - December 1992,[1] there have been two significant advances. At SEP, they have now implemented a nonlinear finite-element routine for calculating stress at critical regions of components. The method is based on a stress-dependent secant modulus, using a damage mechanics formulation developed by Ladeveze from Cachan. This has provided them with a superior capability for designing attachments. The contact there is Pierre Lamicq.

Another group in France, at Lyon, led by Professor Rouby, has conducted a comprehensive study of fatigue on SiC/SiC composites provided by SEP. The main results are the confirmation that a fatigue threshold exists *substantially above* the matrix cracking stress (proportional limit). The threshold of room temperature is about *70% of the ultimate tensile strength* (UTS). They emphasize that this is superior to most alternative structural materials. They associated the threshold with a reduced load-bearing capacity of the fiber, which arises because the interface sliding stress τ decreases during fatigue. The behavior is exactly analogous to that found on Ti matrix composites and in SiC/CAS. Namely, τ reduces to about 1/3 its initial value by cyclic wear of the coatings on the fibers. This smaller τ leads to a lower fiber strength, because the effective gauge length is increased, in accordance with the Curtin global load-sharing model for the UTS. The fatigue threshold correlates well with the predictions of this model. This model is straightforward to implement and could be used for design.

REFERENCE

A.G. Evans, "Ceramic Matrix Composites Programs in France," *ESNIB* **93-05**, 318-323 (1993).

Surface Force Measurements No Longer Limited to Mica: The Universal Force Microscope

by Mufit Akinc, former Liaison Scientist for Materials Science at the Office of Naval Research European Office. Dr. Akinc was on leave from Iowa State University where he is a Profesor of Materials Science and Engineering; he has returned to Iowa State University.

KEYWORDS: surface force; force measurement; adsorption; instrumentation; solid-liquid interface

INTRODUCTION

The surface force apparatus developed by Israelachvili[1] more than a dozen years ago made it possible to measure the force between two surfaces as a function of separation. The technique received overwhelming attention from colloid chemists, surface scientists, and materials scientists alike. For the first time, predictions of DLVO (Derjaguin-Landau-Wervey-Overbeek) theory could be checked experimentally.

The surface force apparatus developed by Israelachvili had one serious limitation: the surfaces that could be used in the experimental measurements had to be thin (2-4 mm), transparent, and atomically smooth. A naturally occurring mineral, muscovite mica, met the criteria—it could be cleaved into thin, atomically smooth sheets. Unfortunately, there are not very many materials like mica that could be used as substrate in these experiments. Consequently, for a long time mica was the only substrate that could be used in measuring surface force. Nevertheless, the technique has been extremely valuable in experimentally verifying DLVO theory predictions and in assessing the effectiveness of various surfactants.

An appartus designed and built by John Parker[1*] at the Institute for Surface Chemistry (YKI), Stockholm, uses a novel technique that allows measurement of force between surfaces other than mica! So far, measurements with glass, silver, and polymer substrates have been demonstrated. The phenomena that will be subject to investigation with this apparatus are too many to list here. A few that may be of interest to the Navy include colloidal processing of ceramics, metal-liquid interactions in corrosive and noncorrosive media, adsorption of surfactants and polymers on various substrates, and adsorption of proteins on living organisms.

SURFACE FORCE APPARATUS

The main purpose of using the original surface force apparatus developed by Israelachvili was to determine the characteristics of liquid film between two mica surfaces and the changes that would be brought about by the addition of a variety of chemicals to the solution. Some of these chemicals are adsorbed on mica surfaces, and the changes in the surface force could be measured as a function of concentration.

The apparatus developed by Israelachvili, and later improved by others, consists of three basic elements:

- a way to control the separation between the surfaces,
- an accurate way to measure the separation between the surfaces, and
- a means to measure the force between the surfaces at a given distance.

An optical interferometer that measures the separation between the fringes of equal chromatic order (FECO) has been used to measure the surface separation. The technique is said to have a resolution of about 0.2 nm. Additionally, the refractive index of the solution between the surfaces can be obtained from the interferometer. On the

[1*]Dr. Parker is on leave from Department of Applied Mathematics, Australian National University, Canberra, Australia. The new apparatus was designed at Australian National University but an improved version is built at the Institute for Surface Chemistry, Stockholm, Sweden, where Dr. Parker is a visiting scientist.

other hand, there are several disadvantages. For the operation of an optical interferometer, surfaces must be thin, transparent, and smooth. Therefore, studies using this technique were limited to mica,which meets all of the above requirements. There were some efforts to measure the surfaces other than mica, by spin coating a layer of material on mica surfaces. The coatings had similar requirements, i.e., they also needed to be thin, transparent, and smooth. In addition, the interface between mica and the coating material must be stable in the solution being immersed.

Surface separation control is achieved by a piezoelectric actuator. The sensitivity of the piezoelectric actuator is quite satisfactory for this purpose. Control of separation better than 0.1 nm is readily achieved; this is better than the interferometer resolution. One of the surfaces is mounted on the actuator and the other on a "soft" spring. Thus, when a voltage is applied on the actuator, one of the surfaces is brought closer to the other. Because of the repulsive force between the surfaces, the spring is compressed to achieve an equilibrium separation. The force between the surfaces is then calculated from the deflection in the spring according to Hooke's law, and the equilibrium separation is measured from the interferometer fringes.

Several deficiencies are associated with force measurement by the spring deflection method. One is instability due to thermal drift; another is the dynamic effect. Since the forces are hardly constant (especially at the scale considered here), dynamic effects may be inadvertently treated as static force. This problem is more serious in viscous fluid, which assumes an equilibrium state much more slowly.

UNIVERSAL FORCE MICROSCOPE

Parker and his co-workers at the Australian National University[2] developed a new version of the surface force apparatus that overcomes much of the limitations of Israelachvili's apparatus. This apparatus uses a piezoelectric bimorph (two slabs of piezoelectric pieces glued together) to measure the force, replacing the mechanical spring of the original apparatus. Figure 1 is a schematic drawing of the bimorph section of the apparatus. This bimorph operates on the principle of a simple canti-

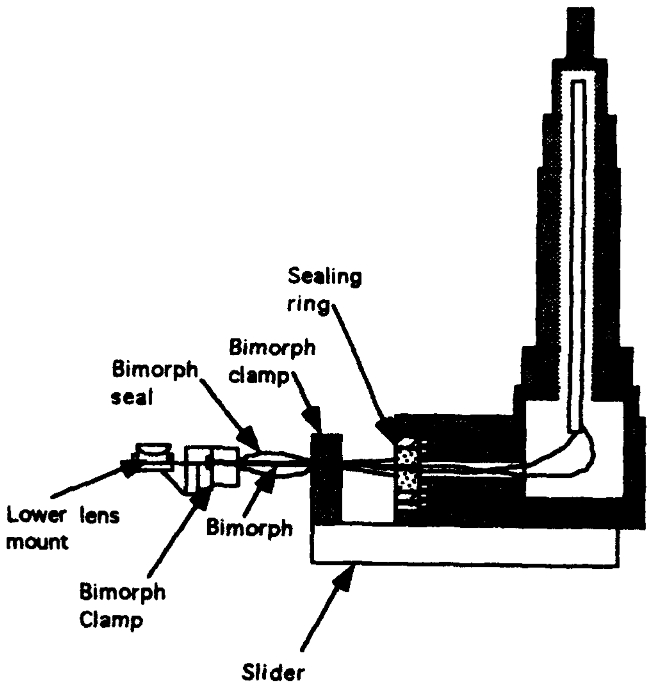

Fig. 1—Schematic diagram of piezo electric bimorph

lever arrangement. When the beam is deflected by an applied force, the upper slab experiences a tension and the lower one is under compression. The voltage V developed between the two slabs is proportional to the deflection; this in turn is proportional to the force between the surfaces.[3] It is therefore possible to induce a deflection on the bimorph by applying a voltage to the separation control actuator; the force between the surface is then measured by the charge in the bimorph. The magnitude of the force is determined by

$$F = \frac{2}{3} \frac{Q}{d_{31}} \frac{T^2}{L}.$$

T and L are the thickness and length of the bimorph, Q is the charge, and d_{31} is the charge constant. By allowing the charge to leak to the ground through a resistor, voltage decays exponentially with a time constant t, making it possible to continuously measure the separation distance between the surfaces.

Response of such a piezoelectric bimorph is also used to determine the separation between the surfaces. The inherent noise in the electronics is

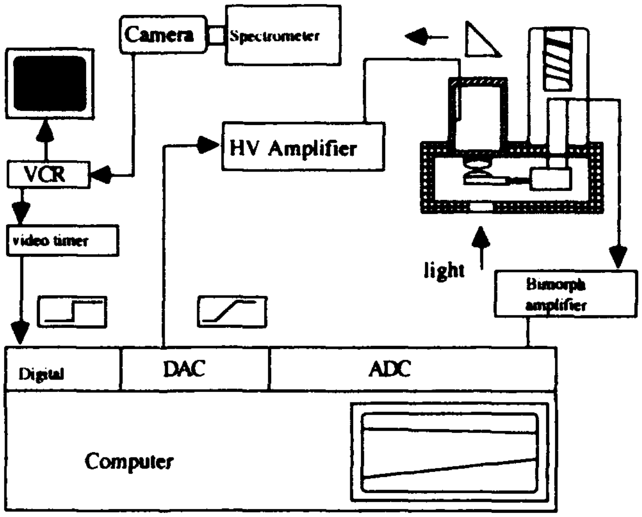

Fig. 2—Schematic diagram of surface force apparatus including FECO system. The system is controlled by a personal computer that receives the information from a video timer for separation measurement and a bimorph for force mesurement. At the same time, the computer drives the piezo actuator for subsequent measurement.

approximately 5 μV, and the piezoelectric has a sensititvity of 150 $\mu V\ nm^{-1}$; this results in an expected resolution of about 0.03 nm. In reality, a resolution of about 0.05 nm is practical. Compared to a resolution of the FECO (0.2 nm), the new technique offers a resolution improvement of at least four fold. Figure 2 is a schematic diagram of the surface force apparatus.

One of the limitations of the new design appears to be that the bimorph's force constant α has to be determined by an external calibration technique. For this, FECO fringes, which were used for measuring the separation in the old version, have been utilized. Once α is determined from the slope of separation versus voltage plot, all subsequent separation measurements are done by voltage measurement. The particular bimorph used in Parker's apparatus shows an excellent linearity between the force and voltage up to 1 V for several repetitive runs. The slope of the *F/R* vs V was determined to be $1.9 \times 10^{-3} N\ m^{-1} V^{-1}$ for the bimorph used. Since the resolution of the electrometer is 5 μV, the minimum detectable force is about $1 \times 10^{-8} N\ m^{-1}$.

EXAMPLES

As a first attempt to measure the surface forces between materials other than mica, Parker demonstrated the instrument by using glass surfaces.[3] Glass was chosen because of its simplicity in preparation. A 2-mm-diameter glass rod was heated in a gas burner until it melted and formed a bead at the end. This piece provided the smooth clean surface for investigation. The radius of the surfaces in this case was about 10× smaller than the one used in Israelachvili's apparatus. This reduced the magnitude of the hydrodynamic force by an order of 100, which means that the surface force can be measured 100× faster. Surface forces were measured as a function of separation in aqueous solutions containing varying concentrations of CTAB (cetyl trimethyl ammonium bromide). The force between the two glass surfaces separated by pure water shows a short-range repulsion resulting from the negative charge that glass surfaces exhibit in neutral pH. At very low concentrations (approx. 10^{-7} M) of CTAB, the short-range repulsion is absent. The surfaces exhibit attractive forces and come to an adhesive contact as they are brought closer together. When the concentration is increased to 10^{-5} M, repulsion forces are set at large separations and forces become attractive at short separations, with adhesive contact at about 8 nm. At still higher concentrations (5×10^{-5}M) the repulsion is completely absent; the surfaces have attractive forces throughout the entire separation range. Figure 3 shows plots of surface force as a function of surface separation at various CTAB concentrations.

The group also demonstrated the applicability of the new technique in measuring the force between the silver surfaces in air, which was impossible in the original apparatus. A thick layer (530 nm) of silver was deposited over mica surfaces and the force between the surfaces was measured as a function of distance in air. A weak attraction, which increased slowly down to 20 nm, followed by a jump to 3 nm, was observed. At smaller separations a strong repulsion was observed. The 3-nm separation was found to be on the order of surface roughness as measured by STM (scanning tunneling microscopy), indicating point contact at surface asperities.

As mentioned, a discontinuous "jump-in" is usually observed as the surfaces are brought together. Similarly, when the surfaces are pulled apart from close approach they show a "jump-out." In a sense, the last part of the attractive force is

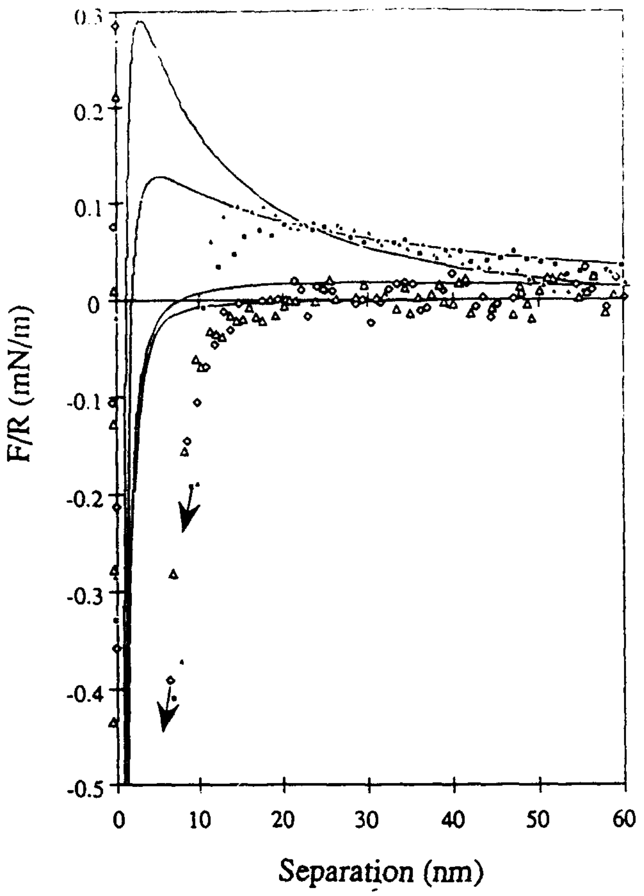

Fig. 3—Example of data obtained by surface force apparatus using the bimorph piezo bimorph. Solid squares represent 9.22 × 10^{-6} M; open triangles and open diamonds correspond to 4.59 × 10^{-5} M; and filled diamonds are 1.36 × 10^{-4} M CTAB concentration. Shaded area represent theoretical plots with constant charge (upper boundary) and constant potential (lower boundary). Surface potential of 22 mV and Debye length of 97.4 nm is assumed.

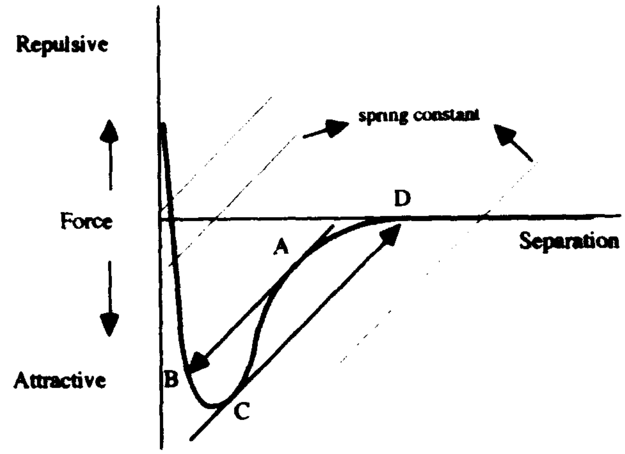

Fig. 4—Schematic force-separation plot indicating jump-in (A to B) and jump-out (C to D). Thus between B and C, the slope of the attraction curve exceeds the force constant of the spring (or coefficient of the bimorph) and data cannot be obtained in this range.

not available for measurement with this technique, as in Israelachvili's apparatus. This is explained by the fact that the total force acting on the system is given by:

$$F_{tot} = F_s - F_b,$$

where F_s is the surface force, and F_b is the bimorph or spring response. At equilibrium, F_{tot}= 0. Data are collected starting, say, from $D = \infty$ down to $D_{crit} = A$ (Fig. 4). At this point, the slope of the surface force exceeds the slope of the bimorph response α (or spring constant k). This causes an instability. Hence the surfaces jump to a closer separation *B*, where the slope of the force curve is equal to that of the bimorph response (or spring constant). A similar jump-out phenomenon is observed when surfaces are brought from close approach to separation. In this case, jump occurs from point C to point D. Thus, data between points C to A are not accessible.

This can be overcome by externally changing the spring constant or bimorph response coefficient. It means an additional term should be present in the above equation that could be activated to maintain the equilibrium along the attractive force-well at all times. This was achieved by positioning a pair of magnetic coils above and below the bimorph so that the magnetic force is aligned to that of the piezo actuator.[5] The magnitude of the additional force can be adjusted by the field applied to the magnetic coils; this allows data to be collected in the high slope portion of the attractive region.

SUMMARY AND OUTLOOK

It appears that a new era in measuring surface force has begun. The design by Parker, based on the original surface force apparatus of Israelachvili, has made it possible to measure forces between surfaces other than mica, it has allowed the whole range of separations to be accessible for measurement. The sensitivity and resolution of the apparatus has been greatly improved, and the measurement can be done much faster than with the original design.

Surfaces under investigation need not be thin or transparent, since the separation measurement does not use FECO fringes. Nevertheless, smooth surfaces are preferred for accurate measurements. Surfaces with roughness of about 3-5 nm have been studied. Examples with glass and silver as well as mica surfaces have been shown. More examples are needed and hopefully forthcoming soon, to give a better idea about the range of applications and limitations.

It was also claimed that the apparatus will determine the surface topology of the materials as well. Because of this claim, the new design has been called the "universal force microscope." I have not seen a demonstration of this capability as yet. The capability of accurately measuring surface separation should make this possible. Once the universal force microscope is implemented into the unit, it will function as a surface force apparatus, a scanning tunnelling microscope, and an atomic force microscope. Of course, it is not clear as yet if the unit will be sufficiently versatile and accurate to replace the individual microscopes currently available.

I have been told that the unit will be commercially available from ANUTECH Pty. Ltd. in Canberra, Australia, later this year.

REFERENCES

1. J.N. Israelachvili and G. E. Adams, "Measurement of Forces Between Two Mica Surfaces in Aqueous Electrolyte Solutions in the Range 0-100 nm," *J. Chemical Society, Faraday Transactions*. **74,** 975 (1978).

2. J.L. Parker, H.K. Christenson, and B.W. Ninham, "Device for Measuring the Force and Separation Between Two Surfaces Down to Molecular Separations," *Review of Scientific Instruments* **60**(10), 3135 (1989).

3. J.L. Parker, "A Novel Method for Measuring the Force Between Two Surfaces in a Surface Force Apparatus," *Langmuir* **8**(2), 551 (1992).

4. J.L. Parker, V.V. Yaminski, and P.M. Claesson, "Surface Forces Between Glass Surfaces in Cetyltrimethylammonium Bromide Solutions," *J. Physical Chemistry* **97**, 7706 (1993).

5. J.L. Parker, and A.M. Stewart, "Force Feedback Measurements of Surface Forces," *Progress in Colloid and Polymer Science* **88**, 162 (1992).

6. *YKI News*, **1993**(1), 6 (1993).

7. J.L. Parker, P. Richetti, P. Kekichef, and S. Sarman, "Direct Measurement of Structural Forces in a Supermolecular Fluid," *Physical Review Letters* **68**(12), 1955 (1992).

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Oceanography

Impressions of Oceanographic Research In Europe: A Summary Report

by John P. Dugan. Dr. Dugan was the Liaison Scientist for Physical Oceanography at the Office of Naval Research European Office. Previously he formed and directed the Field Measurements Department for Areté Associates. Earlier, he was at the Naval Research Laboratory, Washington, DC. He has returned to Areté Associates.

KEYWORDS: European Community programs; coastal ocean forecasting; modeling; communications; facilities

INTRODUCTION

As a result of my two years (June 1991 - June 1993) as the ONR Liaison Scientist for Oceanography in Europe, I have several overall impressions concerning the way in which oceanographic research and development (R&D) is pursued in Europe. There are a number of different emphases that have considerable merit, and we potentially can benefit from studying them. There are strong European Community (EC) programs and jointly funded institutes. There is an increasing trend to look to other EC countries rather than to the United States for collaborative relations and programs. We can expect challenges to our leadership in oceanography in a number of areas, especially in the technology base. In particular, the current European lead in the development and experience in the operations of coastal ocean forecasting systems is five years or more.

NATIONAL AND INTERNATIONAL PROJECTS

First and foremost, the European countries are attempting to unite economically, and this includes the funding of their research programs. The EC has significant financial resources in their Framework Programme that supports many scientific areas, including numerous Marine Sciences and Technology (MAST) projects. These projects are multi-institutional and multi-national. Although the research participants think and behave quite differently, and have even stronger local ties and interests, the countries are embarked on a path toward unifying their science and technology (S&T) efforts.

Whereas the research institutes previously have been funded primarily by their own governments, they naturally have focused on their perceived national interests. Thus, their projects historically have been national, rather than international, in scope. A good example is the North Sea Project that was recently completed under the United Kingdom (U.K.) Natural Environment Research Council (NERC) funding.[1] Only U.K. institutes were invited to coordinate research activities, although obviously many other countries around the North Sea could have been involved in the modeling and observational work. A second example is the Nansen Centennial Drift Project that is being organized by the Norwegians. They had numerous national meetings to decide their goals and approach before they invited other nations to be involved. These projects are first and foremost national ones, and international involvement typically is invited only as a secondary effort at best. However, examples like these seem to be a "dying breed," and great emphasis is being placed on the international projects that are organized around EC funding.

The change to higher percentage of research monies coming from European support of R&D has a direct affect on the orientation of all the sciences, particularly on their interactions with each other and with the U.S. As a result of being required to pay into the EC Science programs, individual national budgets for research are suffering. Thus, the research institutes must compete within the EC for a fraction of the EC Science budget in order to retain their present capabilities. These programs are European programs and are not open for direct participation by U.S. institutions. This forces them to coordinate their work (and proposals for future work) much more carefully with their European colleagues than they have done in the past, and this extra time comes out of other commitments. A primary result is a comparable loss of time to work with colleagues and institutions in the U.S. Thus, there is no escaping the conclusion that it will be more difficult in the future to collaborate with these institutes and scientists than it has been in the past.

An example of the multi-national cooperative research programs is the EC Framework Programme that supports the MArine Science and Technology (MAST) Programme, which is of particular importance to oceanographic S&T. Another good example is in the area of cooperative research agencies, and the European Centre for Medium-Range Weather Forecasts (ECMWF) is a highly successful case in point. It provides midrange weather forecasts to the various national centers in western Europe but, more importantly, it provides a central focus for their weather-related R&D. Many specific research topics (e.g., ocean wave predictions and data assimilation) are undertaken at ECMWF, and research personnel are rotated between the Centre and the various coordinating national weather centers. This is a very interesting approach where the international center gets the best of the science and personnel from each supporting country, and these personnel later return to their home countries with newfound ideas, skills and techniques. In turn, the individual centers are the primary customers for the improved knowledge and products. It appears to me that the U.S. could benefit from a similar organization, with a single lead institute for weather-related R&D, rather than being split among the Department of Commerce (NOAA), the Navy, and the Air Force.

There also is talk of forming a European center for ocean predictions, although there are no specific plans to date to my knowledge. John Woods, the head of the Marine and Atmospheric Sciences Directorate of NERC in the U.K., has lectured on this theme of an EC center for development of ocean models and forecasting system in this decade. Dr. Woods argues that three prerequisites are necessary for ocean forecasting: scientific understanding, computer resources, and high-resolution global databases. Assuming that teraflops computers will be available during the mid-1990s and that the planned Global Ocean Observing System (GOOS) will provide the required data, ocean model development will rapidly evolve toward high-resolution (10 km or better) capability before year 2000. This will enable dynamical-chemical-biological studies to be conducted on issues such as coastal water quality, cross-shelf transport, atmosphere-ocean interaction, and eddy-eddy interaction. By the end of the century, the U.K. plan is for large-scale models to be built. These models are to have high enough resolution to capture local biological feedbacks that are interactive with ocean chemistry and dynamics. Dr. Woods indicates that there is a proposal from the European Committee for Ocean and Polar Sciences (ECOPS) for developing a "European Centre for Research on Ocean Forecasting." This center is planned to be a lead international organization in the development of modeling and forecasting capabilities for the oceanic environment. In my opinion, this is a very enthusiastic projection, and we should expect further developments on this topic from NERC and MAST in the near future.

COMMUNICATIONS

The means of communications among scientists in Europe are much less electronic than is typical in the U.S. This is true especially for scientists in countries of the former Soviet Union.[2] But even in Western Europe, I sense a certain cultural difference that accounts for the apparent slow implementation and use of e-mail by scientists, rather than just a lag behind the U.S. in its acceptance and widespread use.

DEDICATED EXPERIMENTAL FACILITIES

I have been impressed with many of the large, dedicated experimental facilities in Europe. The

U.K. Meteorological Office C-130 Hercules aircraft at Farnborough and tethered balloon facility at Cardington are good examples of facilities that have large, dedicated support staffs.[3] These enable the scientists to focus on their science, while the mundane chores of data capture and preliminary analysis are handled by dedicated support personnel. The difference I perceive is that these chores are supported with significant levels of manpower. The instruments almost always are ready for use, so little effort is wasted in installing or taking down sensors from nondedicated aircraft. This also applies to the research vessels; they often are scheduled by the local institute that operates the vessel rather than by a central agency like UNOLS (the University National Oceanographic Laboratory System) in the U.S. The result is that the support personnel work for the same institute as do the scientists. Significant long-term benefits accrue, presumably with some increase in expense and efficiency compared with the U.S. system where most facilities are centrally scheduled.

Also, there is an interesting relative difference in the number of rotating tank facilities that presently are operating in Europe, including the extremely large facility in Grenoble. These facilities are useful for modeling the effects of Earth's rotation and buoyancy forcing on the ocean circulation and are critical for understanding the complex processes occurring in the complicated topography of coastal seas.

A unique facility in Europe is the ERS-1 satellite that is so widely used for remote sensing of the ocean and sea ice. This facility was enabled by a cooperative effort of all countries contributing to the European Space Agency (ESA). A major stumbling block has been that ESA has funded the satellite but not the infrastructure for handling and processing the data. Thus, this part of the various research projects that depends on the data has been a continual struggle. This shortfall is apparent when compared with the NASA approach that funds both the satellite and ground support systems in their entirety. On the positive side, the existence of the satellite has promoted an enormous European R&D effort in remote sensing of the ocean that is mature enough to go its own way and not depend on the U.S. for its leadership.

Unfortunately, a further aspect of international relations has cropped up a few times in the last year. Several European scientists have questioned the reliability of the U.S. as a partner in cooperative research. This has been voiced particularly in regard to cooperative programs that expect to utilize satellite resources in the U.S. NASA's Earth Observing System (EOS) has been in the plans for some time as a widely advertized program that invites international collaboration. However, annual attacks in Congress have caused a continuing restructuring and retreat in planned capability that is leading to loss of confidence in our ability to deliver. Considering the recent lessons of the Space Shuttle and the Space Station, the future of this environmental program does not look good. Unfortunately, these difficulties are widely publicized in European science circles. They have come up more than just occasionally in informal discussions with scientists during visits to European institutes that work in the area affected by these decisions. The bottom line is that the U.S. is seen to be backing down on previous commitments, so why should scientists now be interested in new ones? This is sour grapes, no doubt, but it should be of concern to U.S. scientists and science managers.

GOVERNMENT/INDUSTRY/RESEARCH INSTITUTE COOPERATION

There is an underlying commitment by European national governments to provide support for oceanographic activities because they view these as important national interests. Probably more so than in the U.S., especially in developmental activities. Thus, there are numerous examples of partial funding for developmental projects that have goals of providing products that can be sold to support a positive balance of payments. Multiple examples in the U.K. involve the Department of Technology and Industry (DTI), which calls itself the "Department for Enterprise." Its purpose, frankly, is to partially fund (typically 50-50 cost split) those R&D programs that have a solid chance of developing markets overseas. For example, DTI and NERC have been funding the development of two separate Autonomous Underwater Vehicles: one that is mid-future, low risk; the other is longer term, higher risk.[4] In addition, DTI has supported the expensive Ocean Surface Current Radar[5] that recently has been successfully marketed to the U.S.

These joint industry-government efforts continue to be directly aimed at marketable technologies.

There also is an strong, continuing interest (particularly in France) in selling observational data from satellite systems to potential users, as opposed to the more typical U.S. stance that makes it freely available to users. This is apparent in the negotiations between U.S. and ESA managers for new cooperative programs.

OPERATIONAL OCEAN FORECASTING CENTERS

A unique aspect of European coastal oceanography is the presence of centers that are funded by the national governments to make ocean forecasts in the coastal zone. These are of interest to the U.S. Navy because they can serve as guides in their successes and failures in providing services to their customers,[6] but they have longer-reaching and perhaps unexpected results. The centers provide a valuable service to researchers in assisting the planning and implementation of observations in the coastal zone, and they provide a readily available source of data.

A particularly bright spot is the extent and quality of the work associated with the operational predictions of the ocean in the countries surrounding the North Sea.

OTHER CENTERS OF EXCELLENCE

As is true in R&D activities everywhere, certain centers of excellence will be more likely to make the breakthroughs in science and technology than others. In the ocean sciences, there are a few really bright spots that should be mentioned. First, in the area of "big thinkers," several individuals and their organizations stand out. Professor Klaus Hasselmann at the Max-Planck-Institute for Meteorology in Hamburg, Professor Wiin Nielsen of the Geophysics Institute in Copenhagen, and Professor Ola Johannessen at the Nansen Environmental and Remote Sensing Center in Bergen top my list.

COLLECTION, ASSESSMENT, AND DISSEMINATION OF EUROPEAN S&T INFORMATION

The development of organized strategies by the EC in S&T affairs has caused the U.S. National Science Board (NSB) to assess this situation and to make several recommendations to the National Science Foundation.[2] The recommendation that is important here concerns the collection, assessment, and dissemination of European S&T information. The essential issue identified by the NSB committee is how to increase the quantity and quality of information and assessment on European S&T, particularly timely information for policymakers and public users. Specific recommendations for the U.S. and the NSF were:

- the U.S. government should strongly consider expanding its human and technical resources devoted to, and raising the priority assigned to, the collection, reporting, assessment, and dissemination of information on European science and technology structures, activities, and capabilities, particularly in the context of evolving European integration; and
- NSF should give particular attention to increasing its capability to provide information and assessments of S&T in Europe, with greater attention given to multilateral cooperation in the region. NSF should be encouraged to utilize effectively its existing information, assessment, and policy-support capabilities to expand the scope of cooperation with Europe.

The Office of Naval Research has provided the U.S. Navy and the rest of the U.S. R&D community with some significant fraction of these capabilities since its formation in 1946. A major part of this is in the Foreign Field Offices (FFOs) in London and Tokyo. However, ONR presently is being reorganized, and its response to these needs is not clear. Both the structure of the FFOs and the format of reports (such as *ESNIB*) are under review, and the results will be known in the near future.

REFERENCES

1. J.P. Dugan and T.H. Kinder, "Coastal Oceanography Research at the Proudman Oceanographic Laboratory," *ESNIB* **93-02**, 142-150 (1993).

2. J.P. Dugan, "Final Report for Assessments of Oceanographic Institutes of the Former Soviet Union," *ESNIB* **93-03**, 157-160 (1993).

3. J.P. Dugan, "Airborne Boundary Layer Turbulence Research — Unique United Kingdom Capabilities," *ESNIB* **92-04**, 180-188 (1992).

4. J.P. Dugan and J. Sampson, "Autonomous Underwater Vehicle Programs for Oceanographic Surveys and Research in the U.K.," *ESNIB* **92-04**, 176-180 (1992).

5. L. Jendro, "Survey of European Surface Current Radar Systems," *ESNIB* **92-05**, 207-216 (1992).

6. J.P. Dugan, "Assessment of Coastal Ocean Forecasting Systems in Europe. Part 1," *ESNIB* **93-06**, 365-392 (1993), and Part 2, **ESNIB**, this issue.

7. *Science and Technology Integration in Europe and Influences on US-European Cooperation* (National Science Board, Nov. 1990).

Ocean-Shelf Coupling and Exchange: A Workshop on Important Ocean Physics Processes at the Shelf Edge

by J.P. Dugan and T.H. Kinder. CAPT Thomas H. Kinder, USNR, Ph.D., was a visiting scientist/reserve officer to the Office of Naval Research European Office. CAPT Kinder is Director, Reserve Technology Mobilization, Office of the Chief of Naval Research; Dr. Kinder is Manager, Coastal Sciences Program, Office of Naval Research (ONR), Arlington, Virginia.

KEYWORDS: shelf-edge processes; boundary layers; tidal mechanisms; frontal instabilities; dynamical coupling

INTRODUCTION

There is an increasing recognition that processes at the edge of the continental shelves are important in the dynamical coupling and in the exchange of water and its properties between the shelf and the adjacent ocean. These processes affect circulation on the shelves, availability of nutrients, distribution of sediments, and transport of natural and anthropogenic products into the deep sea. We must begin to understand these processes; they will allow us to better understand our climate. This, in turn, will allow us to improve the models that are the basis for forecasting ocean conditions in the coastal zone.

It is timely to determine what can be done about this specific problem and also for U.S. scientists to learn of the plans for several European programs focused on this area. Therefore, a workshop on this topic was planned by the Office of Naval Research European Office (ONREUR) and the Proudman Oceanographic Laboratory [United Kingdom (U.K.)]. It was jointly sponsored by the Office of Naval Research (ONR) and the U.K. National Environment Research Council (NERC) and was held 10-11 May 1993 at the Proudman Oceanographic Laboratory at the invitation of Dr. John Huthnance, head of the Marine Physics Group. About one dozen each of European and U.S. scientists attended.

GOALS

The objectives of the workshop were to improve physical understanding and modeling capability for shelf-edge processes. The emphasis was on understanding the processes rather than their ramifications. Attendees were charged to assess present understanding of shelf edge processes, identify critical knowledge gaps, identify tractable research problems, and explore U.S.-European collaboration. A secondary objective was to learn of upcoming research programs in Europe and the U.S. Interdisciplinary contributions were solicited, but in the end the workshop was dominated by physical oceanographers.

SCIENTIFIC ISSUES

Oceanic flows are forced by buoyancy, wind stress, and the tides, and they are modified by lateral and bottom boundaries. Even with similar forcing, the open ocean and shelf display different phenomena (e.g., Rossby waves versus shelf waves). Large gradients across the continental slope may themselves result in new phenomena (e.g., the barotropic tide-forcing large-amplitude internal waves). These physical processes are important for many climatic, water quality, and natural resource issues. The motion of the water and the effective residence time on the shelves affect the exchange of properties and materials between the continents and the deep sea. The constituents of particular interest include organic carbon, nutrients, dissolved gases, and anthropogenic and natural pollutants.

Up to now, research has concentrated on either the deep ocean or the shallow shelf. Thus, researchers have naturally (and fruitfully) considered the shelf edge as a boundary of their specific region of interest. This is especially true in the case of numerical models. The shelf edge has typically been approximated by a boundary, either as a vertical wall with specified stresses and fluxes or some softer approximation to a boundary. This is demonstrably not adequate for understanding many of the problems that depend intimately on the processes that are occurring at the edge. Thus, there is an emerging realization that issues and processes associated with the edge demand special consideration—with connections with the shelf on one side and the open ocean on the other. It is unlikely that attending to model deficiencies (e.g., the so-called sigma coordinates that follow the depth changes but may generate spurious pressure gradients and may have poor boundary layer resolution) alone will enable the models to incorporate the appropriate physics that connect the slope and shelf zones. To assess shelf-ocean coupling and to construct models of the exchange in specific regions, the mechanisms must be understood.

Enough is known about mechanisms that contribute to shelf-ocean linkage to put forward hypotheses and to suggest areas of research. For instance, consider two different shelf situations: the U.S. West Coast (northern California), and the U.S. East Coast north of Cape Hatteras (i.e., the Middle Atlantic Bight, where the Gulf Stream no longer impinges directly on the continental slope). The northern California shelf is narrow, and the flow is dominated by wind-driven features: coastal jets, upwelling fronts, and offshore-directed filaments. These mesoscale features probably dominate the communication between coastal and open ocean through eddy shedding, small-scale exchange during current meanders, or through coastal jet separation. On the broad Middle Atlantic Bight shelf, the shelfbreak coincides with a robust front. Shelf-ocean linkage may involve a detached boundary bottom boundary layer, frontal instabilities, or small-scale exchange across the front. Tidal processes, including internal wave generation, also are locally energetic, so that processes such as rectified tidal currents may be critical.

Other shelves in the world ocean show marked similarities to California and the Middle Atlantic Bight (which are taken as examples only), so we see real hope in understanding physical processes that lead to linkage and exchange. On the other hand, additional candidate "prototypical" shelves come to mind, such as the tidally energetic Celtic Sea that was prominent in the discussions, and participants did not attempt a comprehensive taxonomy. Three overlapping areas appeared to generate the most excitement for early progress:

- *Bottom boundary layer physics* has been implicated in shelfbreak frontogenesis, and it is possible that cross-shelf transport is concentrated there. Many multidisciplinary problems (e.g., sediment mechanics, benthic ecology) arise there; instrumentation is maturing; and numerical models can now accept realistic boundary layers.
- *Frontal instabilities* include shedding large eddies and sub-mesoscale processes. The details of cross-frontal circulations are relatively unknown, but instrumentation and modeling capability make such studies possible. Observations that physical fronts are the locations of elevated biological processes, as well as biological and geological boundaries, motivate strong interest.

- *Tidal mechanisms* include internal tide generation, tidal-stirred fronts, large-amplitude internal wave packets, and tidal rectification. There are startling observations of very strong, mean cross-isobath flows that appear to be of tidal origin and which may advect water parcels. Tidal energy often dominates the mechanical mixing energy (and bottom stress), which may then control larger scale processes (e.g., through stratification).

We have deliberately given short shrift to two well-known categories of processes: *upwelling filaments* and *western boundary current interactions*. We feel that these two important categories are better understood, or at least better documented, than the other three; both this judgement and the five categories themselves are open to question, and we hope that the workshop and this report stimulate a constructive scientific debate.

The workshop concentrated on the physics, but attempted to be sensitive to the needs of other disciplines and to the contributions that they can make to the understanding. The participants felt that increased physical understanding will contribute to answering important biogeochemcial questions and that multidisciplinary research opportunities will arise naturally.

Leaders of upcoming European programs provided overviews of their goals and activities: the Shelf Edge Study (SES) in the U.K. Land-Ocean Interaction Study (LOIS) project by Dr. Huthnance, and the European Community (EC) MAST European Ocean Margin EXchange (OMEX) program by Roland Wollast. An additional EC MAST program that will be focussing on an interdisciplinary approach to shelf edge issues [Multidisciplinary Oceanographic Research at the Eastern Boundary of the North Atlantic (MORENA)] was not reviewed.

CONCLUSIONS

It is clear that a plethora of processes occur near the shelf edge that potentially have a primary impact on the exchange of water and materials between the shallow and deep seas. No consensus could be obtained on an identification of the dominant one, nor even on a reasonable prioritized list of them.

Capabilities of shelf and deep-sea numerical models are increasing. There is strong interest in including the shelf edge (and its associated processes) directly into the models rather than as a boundary (either to seaward or shelfward) of the primary domain of previous models. This evolution of models will continue, but there is recognition that they may not necessarily include the appropriate physics for this complex domain. To crack this problem, there clearly is a need for focused, process-oriented research programs that include a critical mass of numerical and physical modeling as well as observational activity. Disciplines other than physics have strong interests and problems at the shelf edge, and potential programs should be multidisciplinary to the extent that mutual benefits are clear.

There was a consensus that the shelf edge deserves a sharper focus on the physical processes than they have received to date. It is a particularly difficult area, and advances in our understanding will be modest unless we abandon our present slow approach to the edge from the two communities that work comfortably on either side of it. Both increased physical understanding and increased modeling capability are required. It is not clear whether incremental improvements in present standard models will suffice, or whether innovation will be required. The ultimate goal is to understand the ocean-slope-shelf as a system; numerical models will play a key role.

Synopses and conclusions of the meeting are available: "Ocean Shelf Coupling and Exchange," J.M. Hufnance, ed., POL Internal Document No. 33, August 1993, Proudman Oceanographic Laboratory, 112 pp.

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European Community Autonomous Underwater Vehicle Programs

by CDR John A. Sampson, USN, former Office of Naval Research European Office Undersea Systems Liaison Officer

KEYWORDS: MARIUS; AUV; vehicle projects; surveys and inspections; unmanned vehicle

INTRODUCTION

The European Community has recently initiated two MArine Science and Technology (MAST) research programs aimed at furthering autonomous underwater vehicle (AUV) technology:

- Advanced Systems Research for Unmanned Autonomous Underwater Vehicles
- Autonomous Underwater Vehicle for Coastal Waters Surveys.

The first project concentrates on generic AUV technologies in direct support of individual major vehicle projects at United Kingdom (U.K.) and French national oceanographic research institutes. The second project is actually building a vehicle (MARIUS - MARIne Utility vehicle System) for coastal seabed inspections and environmental surveys. This report is based on information published by the European Commission and personal visits to some of the key participants.

ADVANCED SYSTEMS RESEARCH FOR UNMANNED AUTONOMOUS UNDERWATER VEHICLES

Participants in this project include some of the major U.K. and French players in this field:

- United Kingdom
  - Institute of Ocean Sciences Deacon Laboratory (IOSDL)
  - Defence Research Agency (DRA)
- France
  - Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER)
  - Société ECA
  - Institut National de Recherche en Informatique et en Automatique (INRIA)
- Greece
  - National Technical University of Athens (NTUA)
- Portugal
  - Instituto Hidrográfico (IH)

The project is tackling three main problem areas:

- hull structural design and materials;
- sensor platform design and dynamic control; and
- self navigation.

Hull Structural Design and Materials

The focus here is on the use of filament-wound composite materials for deep-diving (i.e., 6000-meter) vehicle pressure hulls, especially under high cyclic loading conditions. (These conditions will be encountered by the Institute of Oceanographic Sciences Deacon Laboratory's DOLPHIN autosub, which is intended to continuously fly a sawtooth pattern from the surface to 6000 meters; see J.A. Sampson, "The AUTOSUB Project," *ESNIB* **93-06**, 409-413 (1993).) Items being investigated include the relationship of thick-section winding techniques on the incidence of defects (e.g., air bubble entrainment along the filament), the effects of defect density and size distribution on hull material characteristics, and the effects of seawater on strength, elasticity, creep and fatigue.

Sensor Platform Design and Dynamic Control

The goal in this area is to develop a detailed description of the interdependency of vehicle architecture, major subsystems (e.g., sensors, navigation, propulsion, control), the operating environment, and the mission profile for near-bottom survey vehicles. With this description, it should then be possible to derive a set of guidelines to aid in the design of future autonomous survey vehicles.

Self Navigation

Autonomous deep-survey vehicles require accurate position information. Frequent global positioning system (GPS) fixes are an option, but the time (and energy) spent transiting up to the surface, getting the fix, and regaining track can seriously degrade the overall cost-effectiveness of the system. A reasonable compromise would seem to be a navigation system that could operate with an interval of 2 to 3 days or more between GPS fixes. This project includes a comparative study of available bottom-referenced doppler correlation systems, particularly at depth over rugged terrain, as well a study of the feasibility of using long-range, long-baseline acoustic transponder systems in the deep ocean.

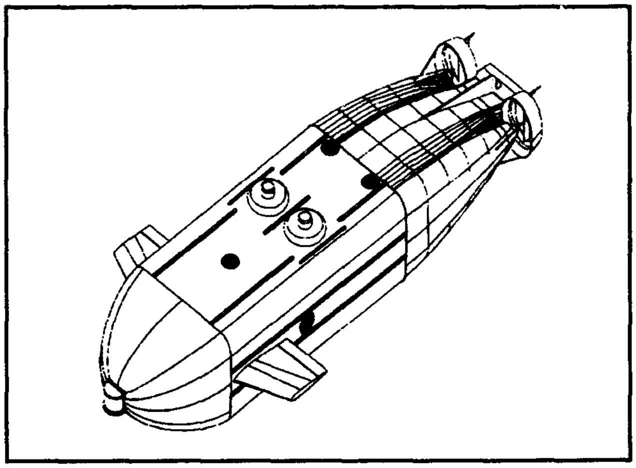
AUTONOMOUS UNDERWATER VEHICLE FOR COASTAL WATERS SURVEYS

Participants in this project are:

- Portugal
  - Instituto Superior Técnico (IST) (project coordinator) - dynamic control and computer systems
- Denmark
  - COWIconsult - prototype vehicle design and testing
  - Reson System AS - navigation/obstacle avoidance sonar
  - Gemoconsult (subcontractor) - vehicle construction
  - Technical University of Denmark (proposed partner)
- France
  - Thomson Sintra Activities Sous-Marines - mission management system
  - Orca Instrumentation - acoustic naviga tion and communications
  - International Laboratory of Marine Cell Biology (LIBM) - applications, payload specifications.

MARINE UTILITY VEHICLE SYSTEM (MARIUS)

The MARIUS vehicle is designed for seabed inspections and environmental surveys in coastal waters less than 600 meters deep. The vehicle is capable of hovering and retrieving bottom samples. The hull has been completed, and initial sea trials are expected off Portugal later this year. It is planned to be fully operational by the end of 1994.



MARIUS

Basic MARIUS specifications are:

Depth	600 meters
Speed	2-4 meters/second
Range	50 km
Mission duration	approx. 6 hours
Batteries	lead-acid
Propulsion	2 propulsors 3 vertical thrustors 1 lateral thrustors (750-watt shaft power)
Control surfaces	twin rudders, elevator, ailerons
Motion sensors	gyro-stabilized compass, accelerometers, pendu- lum, rate gyros, doppler velocity log, speed log
Acoustic comms	50 kHz, 100 bits per second, 1-km range

Navigation	long-baseline acoustic, bottom-referenced doppler, and/or pipeline tracking	
Computer	Gespac Motorola MC68030/25 MHz processors	

From information available to date, the vehicle hardware appears conventional and generally "off-the-shelf." Any major innovations to come out of this project would probably be in the computer control and mission management areas. Especially interesting is the attempt to integrate the excellent high-resolution data from the Reson SEABAT sonar into the mission management system for real-time, autonomous decision making.

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